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EOSR NO. 1608

FINAL REPORT MM&T FOR LINEAR RESONANT COOLER VOLUME I OF II

AD-A207 235

Dr. R. Narayan and J. Silvestro
Magnavox Government and Industrial Electronics Company
46 Industrial Avenue
Mahwah, N.J. 07430

2 February 1989

Final Report For October 1984 to September 1986

Prepared For
U.S. Army Communications-Electronics Command (CECOM)
Fort Monmouth, N.J. 07703-5000

U.S. Army Center For Night Vision & Electro-Optics
Fort Belvoir, Va. 22060

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This final report describes the progress made by Magnavox EOS towards accomplishing the objectives of Contract No. DAAK20-84-C-0440. The three-fold objectives of this contract were to: 1) enhance the producibility and performance of the prototype cooler design developed in a prior contract, b) qualify the design to the target specification in the contract (basically the HD1045/UA B2 specification amended for 2,500 hour MTTF and low audible noise), and c) develop and demonstrate a pilot production facility for the cooler.

Technical difficulties and cost growth related to objectives a) and b) above precluded accomplishing c) as part of this contract's activities. Nevertheless, performance within or exceeding all major requirements has been demonstrated, and Magnavox EOS is currently producing the cooler for use on a U.S. Air Force airborne IR system.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF APPENDICES

1.0 EXECUTIVE SUMMARY

This final report describes the progress made by Magnavox EOS towards accomplishing the objectives of Contract No. DAAK20-84-C-0440.

The three-fold objectives of the contract were to: 1) enhance the producibility and performance of the prototype linear-drive Stirling cycle cooler design established in a prior contract, 2) qualify the design to the target specification in the contract (basically the HD1045/UA B2 specification amended for greatly enhanced reliability [2,500 hour MTTF] and low audible noise), and 3) develop and demonstrate a pilot production facility for the cooler.

Technical difficulties and cost growth related to objectives 1) and 2) precluded accomplishing objective 3) as part of this contract. Nevertheless, Magnavox used its own funds to establish a production facility for the product. While no pilot line demonstration or validation occurred as part of this contract, Magnavox EOS is currently producing and delivering the cooler for use on a U.S. Air Force Airborne IR system. Over 100 coolers have been delivered to date.

Performance within or exceeding the technical requirements established were demonstrated with minor exceptions. The capability of the product to meet the key reliability requirement was demonstrated, as was its ability to meet the stringent cooling performance, efficiency and weight objectives. The cooler proved its durability by passing all thermal and mechanical environmental tests. The EMI emanations from the cooler were demonstrated to be far lower than those of any prior cooler with internal cooler electronics. Small deviations were noted from the design requirements at only two test conditions. Similarly, the audible noise emanations from the cooler were demonstrated to be far lower than those of any prior cooler. A small deviation from the requirement was observed at the 8,000 Hz center frequency on two units.

Hence, the reliable, producible, linear-drive split-Stirling cooler desired by DoD is now a reality.

2.0 INTRODUCTION

The military's need for thermal imaging and electro-optical sensor systems is well known. Proper cryogenic cooling of the detectors remains one of the most challenging technical problems in this field. Weight and power limitations are severe, and high performance from the cooler, in both the technical and economic (life cycle cost) sense, is essential. Cryogenic coolers in fielded systems earned their reputation as the "weak-link" in IR systems, particularly with respect to service life. More reliable, more efficient, lower cost coolers with a wider range of refrigeration capacities are needed by the DoD.

In 1981 Magnavox introduced the linear-drive, all clearance seal technology cooler to the U.S. marketplace. This proprietary technology had been shown to have service life without maintenance measured in thousands, not merely hundreds of hours.

In October 1982, under contract to the U.S. Army (DAAK-82-C-0223) Magnavox began development of a linear-drive cooler compatible with the performance and size requirements of the HD1045/UA 1/4 watt split Stirling cooler B2 specification. The objective of this program was to demonstrate that our multi-thousand hour technology, proven in three prior generations of non-common module linear coolers, could successfully be applied given severe size and performance constraints. In summary, performance testing of these three prototype units demonstrated performance in compliance with all requirements of the contract. The life test results served to support the contention that linear cooler technology is capable of multi-thousand hours of operation in the field without service or failure.

In October 1984 Magnavox was awarded the subject follow-on program (DAAK-84-C-0440) with the three-fold objective of: 1) enhance the producibility and performance of the prototype linear-drive Stirling cycle cooler design established in a prior contract, 2) qualify the design to the target specification in the contract (basically the HD1045/UA B2 specification amended for greatly enhanced reliability [2,500 hour MTTF] and low audible noise), and 3) develop and demonstrate a pilot production facility for the cooler.

3.0 TECHNICAL DISCUSSION

This section presents the design of the cooler in the key areas of thermodynamics, linear motor, power/control electronics, vibration absorber, reliability and producibility.

Figures 3.0-1, 2, and 3 are illustrations, respectively, of the internal cold finger construction, internal compressor construction and cooler outline. Figure 3.0-4 is a photograph of the final cooler design.

In all areas, the starting point for the design was the prototype cooler design established and tested under prior contract DAAK70-82-C-0223.

3.1 THERMODYNAMIC DESIGN

Table 3.1-1 enumerates the key design requirements which were considered in the optimization of the cooler, and contrasts them with those applicable to the prior prototype cooler design.

Note that the cold-tip temperature requirement was made 80°K instead of the prior 85°K. Since the prior prototype coolers demonstrated close to, but less than 80°K with rated heat load in the 71°C environment, improvement of the cold production margin was sought and achieved. This cooling margin improvement came from modification to the thermodynamic design and the linear motor design. The stroke of the compressor piston was increased to perform more compressive work on the gas, while the motor efficiency was enhanced so that the increased compression work was produced with no more input power than previously required.

Table 3.1-2 lists the generic design features which characterize our linear cooler.

Tables 3.1-3 and 3.1-4 give the key dimensions which characterize the compressor and expander respectively. Note the long clearance seal in the compressor which serves both as a gas seal and guide bearing. Note as well the small piston diameter, minimizing the loss of iron cross-section in the linear motor magnetic circuits.

The cold finger dimensions conform exactly to the requirements. Stainless steel screen is used as the regenerator packing.

3.2 LINEAR MOTOR DESIGN

The design of the linear motor is constrained to be consistent with the dimensional, efficiency, and electrical requirements facing the end-product.

To meet the diameter constraint, a radially-oriented magnetic circuit is used, with the motor centered about the compressor piston, as shown in Figure 3.2-1. This offers obvious piston guide bearing performance advantages.

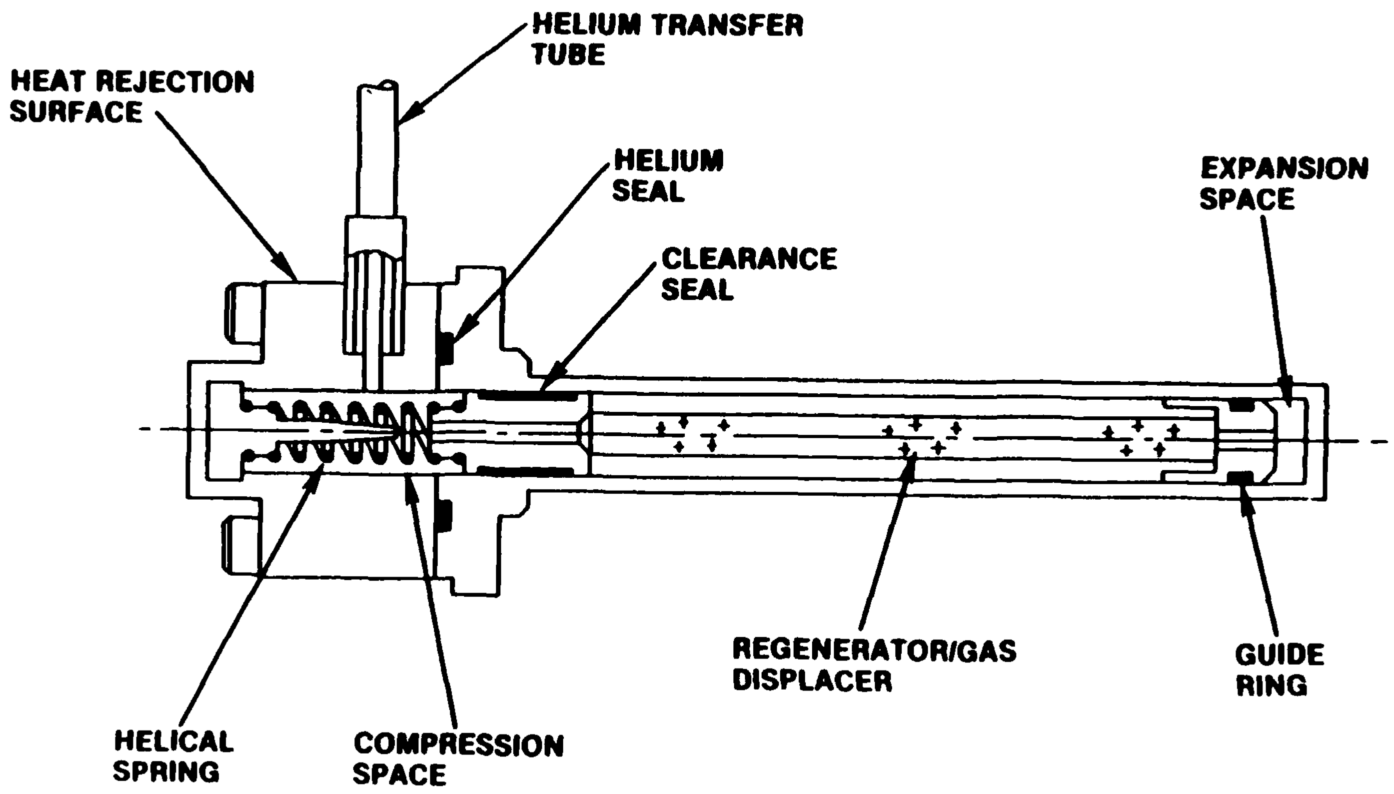

Figure 3.0-1. Illustration of Magnavox Linear Cooler Cold Finger

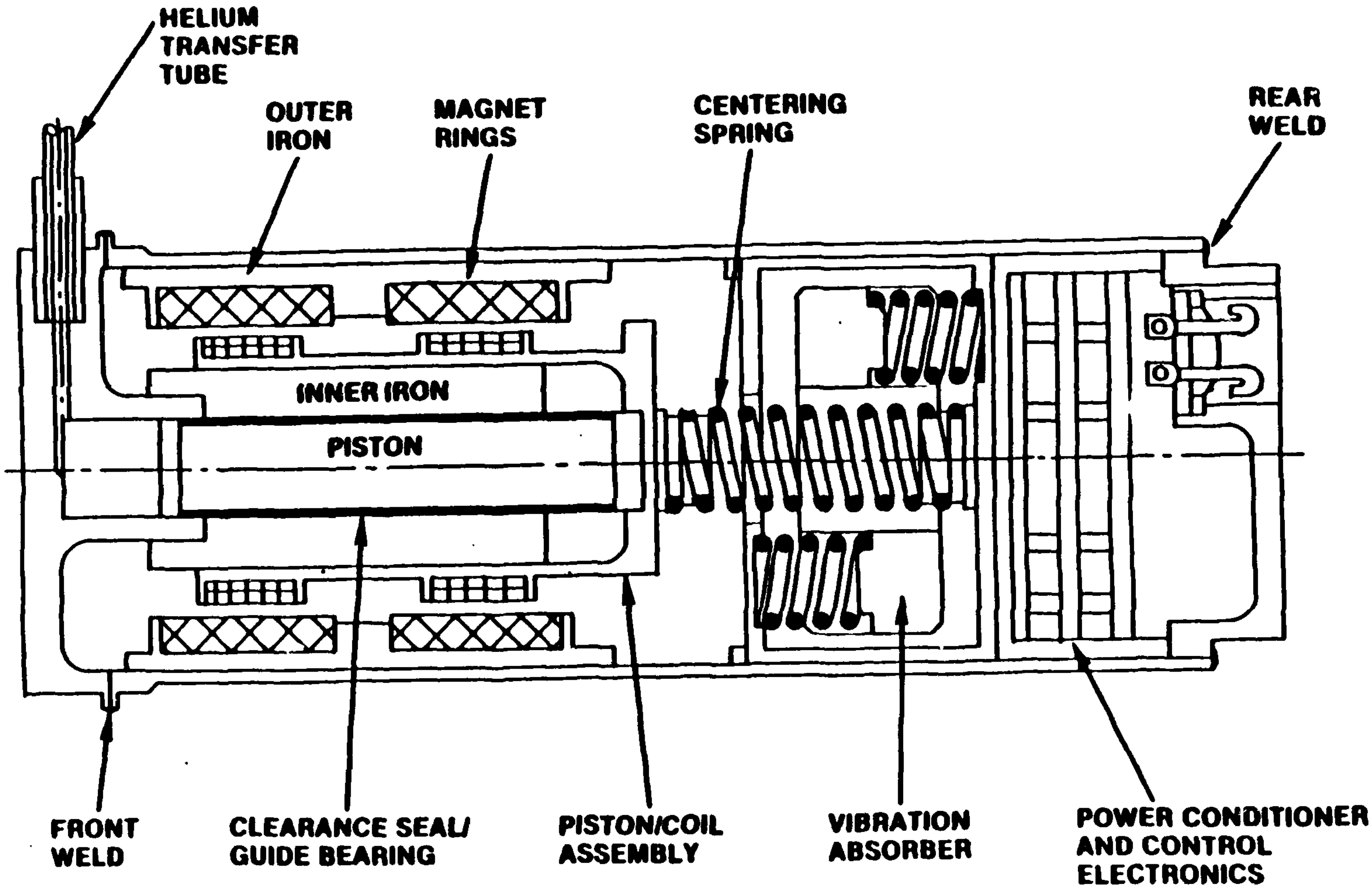

Figure 3.0-2. Illustration of Magnavox Linear Cooler Compressor

NOTES: INTERPRET IN ACCORDANCE WITH DOD STD 100 AND ANSI Y14.5.

1. MANUFACTURE ASSEMBLE AND TEST IN ACCORDANCE WITH NVL SPECIFICATION 82-28A050122A WITH AMENDMENT I, 1 APR '84.

[2] PURGE PORT PLUG SHALL CONTAIN A .125 HEX SOCKET x .07-.09 DEEP.

[3] DIMENSIONS APPLY WITH PURGE PORT PLUG FULLY SEATED (CLOSED).

[4] HEADER TERMINAL SHALL BE ORIENTED SO THAT THE POSITIVE (+) TERMINAL IS LOCATED FROM STRAIGHT UP TO 45° CW OFF THE VERTICAL PLANE.

[5] POTTING TO BE EMERSON CUMING 100 PARTS STYCAST 2741 TO 125 PARTS CATALYST 15.

[6] USER MUST UTILIZE ALL HEAT REJECTION SURFACES SHOWN FOR PROPER SYSTEM INTEGRATION.

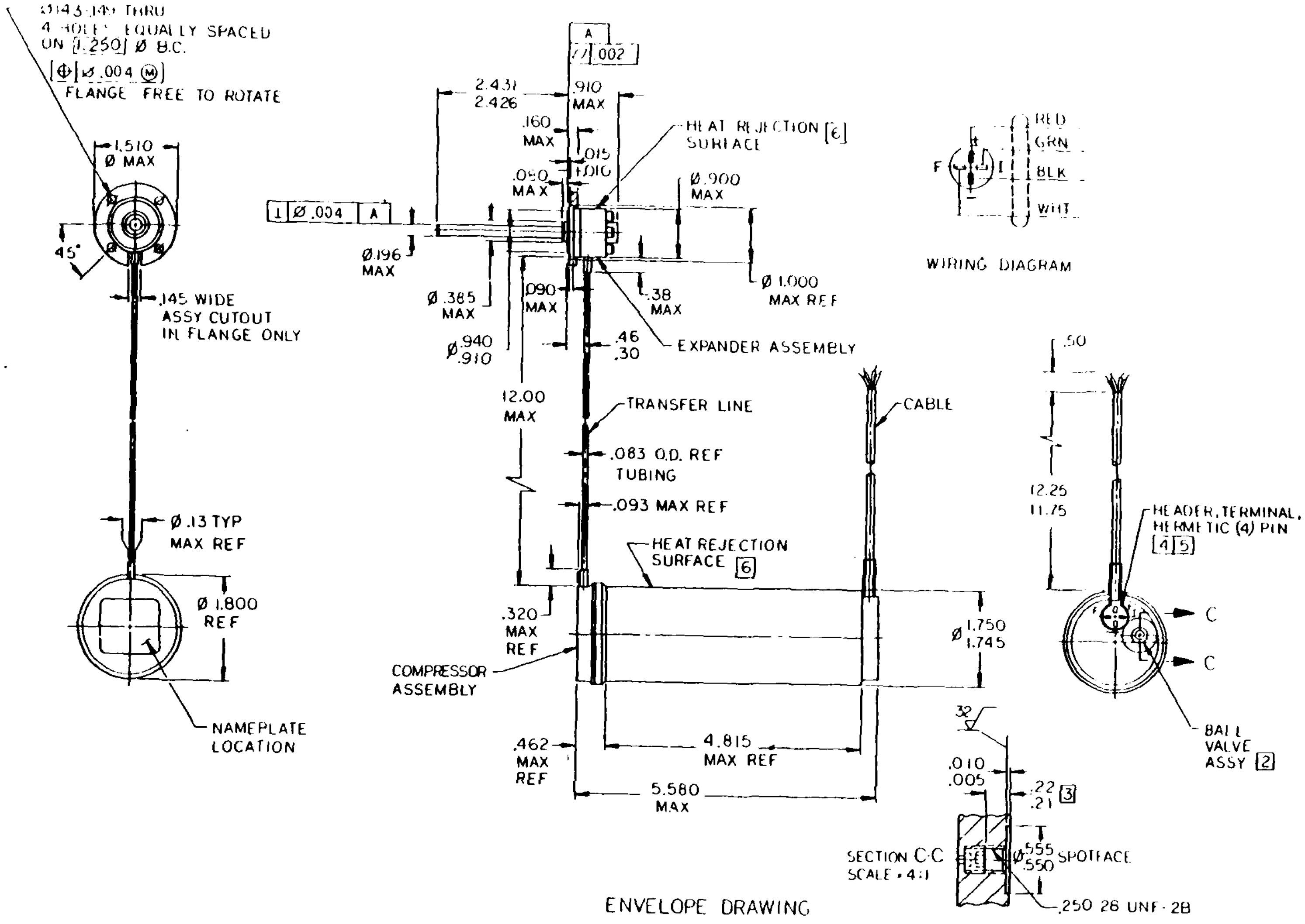

Figure 3.0-3. Outline Drawing

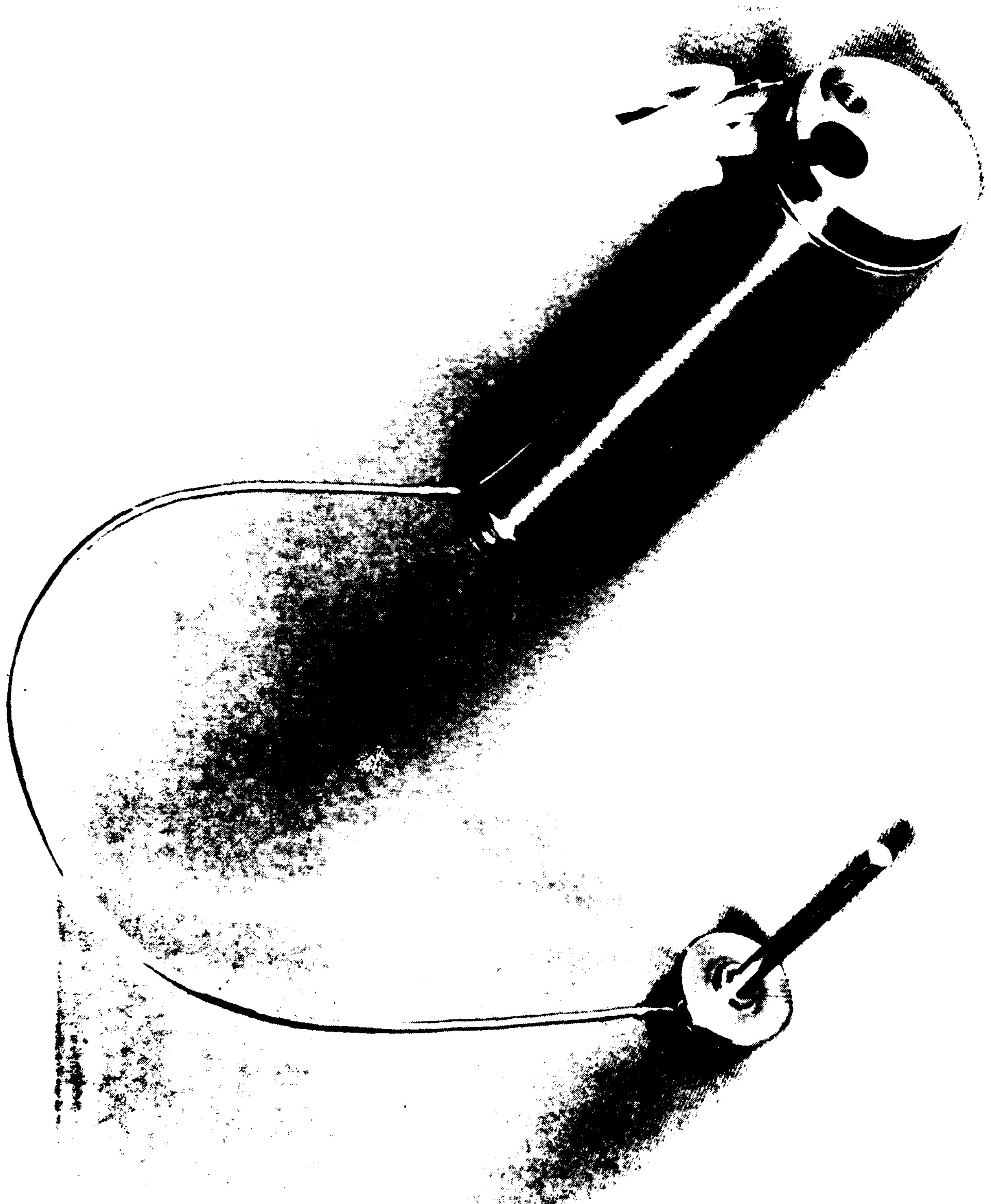

Figure 3.0-4. Photograph of the Linear Cooler

Table 3.1-1. Thermo/Mechanical Design Requirements

Item	MM&T Contract	Prior Contract
Refrigeration	0.35 W at 80°K Max (-40°C to +55°C) 0.2 W at 80°K Max (71°C)	0.25W at 85°K (-40°C to +55°C) 0.20 W at 85°K Max (71°C)
Sink Temperature	-40°C to 71°C	Same
Input Power	30 Watts Max (-40°C to +55°C) 35 Watts Max (71°C)	Same Same
Size	Drawing SM-D-808551 with 12 inches transfer line from expander to compressor	Same
Weight	2.5 pounds Max.	Same

Table 3.1-2. Design Features

1. Single stage Stirling machine with free displacer and driven piston using helium as working fluid.

2. Stainless steel mesh regenerator housed in epoxy glass tube.

3. Spring-restored displacer.

4. Reciprocating piston driven by linear motor.

5. Vibration absorber and electronics drive assembly located in compressor housing.

Table 3.1-3. Key Compressor Design Parameters

Piston Diameter	0.38"
Maximum Amplitude	0.28"
Minimum Piston Seal Length	1.180"
Piston Speed	54 Hz

Table 3.1-4. Key Expander Design Parameters

<u>Displacer Parameters</u>

Diameter	0.185"
Maximum Amplitude	0.100"

<u>Regenerator</u>

Stainless steel mesh in epoxy glass housing

Length	1.970"
Cross-Section	0.0166 In^2
Housing Outside Diameter	0.178"
Housing Wall Thickness	0.016"

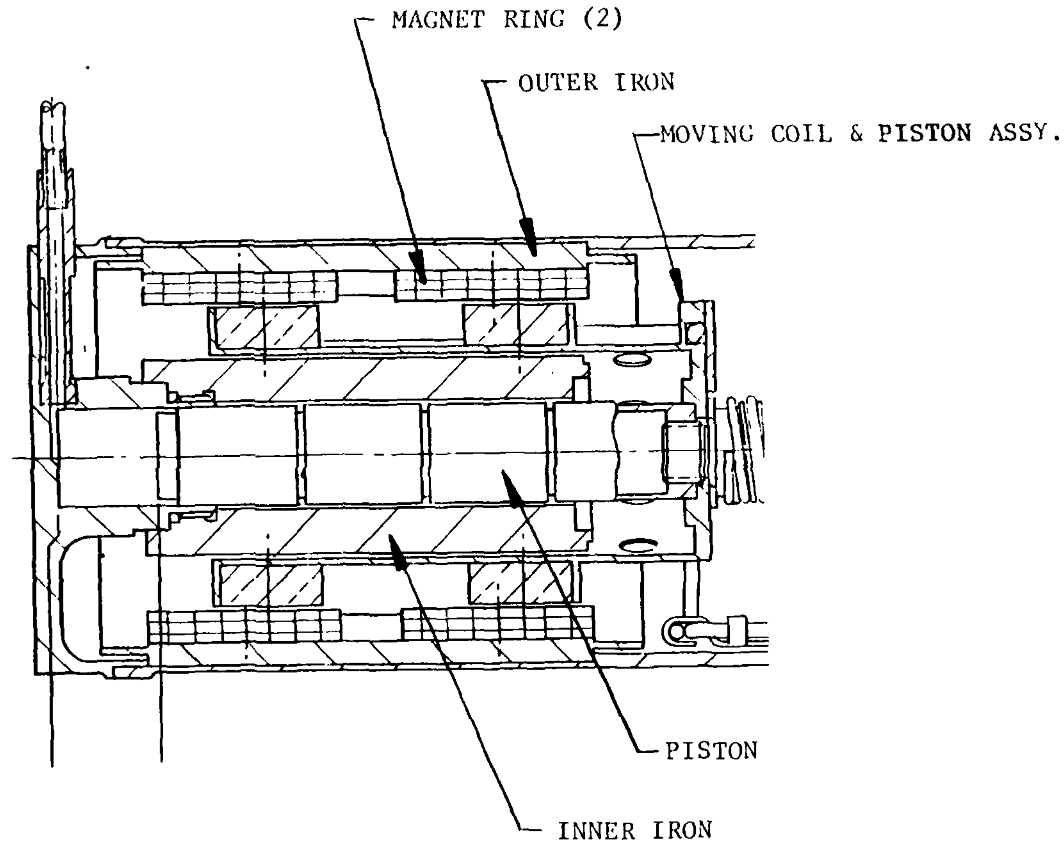

Figure 3.2-1. Linear Motor Design

Note in Figure 3.2-1 the patented "moving-coil" construction; note also that the magnet circuit consists of two radially magnetized magnet rings and two coil spaces (air gaps). Samarium cobalt magnets are used; the motor iron is made of 2V-permendure (a high cobalt alloy).

The physical parameters of the motor construction are presented in Table 3.2-1.

3.3 POWER/CONTROL ELECTRONICS DESIGN

During the contract, the electronics were moved from a relatively large volume discrete-component pc board design, to a custom hybrid microcircuit design housed in the helium ambient inside the compressor. Hybrid technology was used to meet the size and volume limitations of the compressor. The design was augmented to permit operation from a filtered 17-32 Vdc power bus, instead of a preregulated and filtered 17-18 Vdc bus as had been the earlier case.

The design was augmented as well to permit refrigeration output control by the user via an external control line imput.

The major requirements for the electronics are summarized in Table 3.3-1.

The linear resonant motor requires a bipolar drive signal. An alternating voltage applied to the motor terminal causes the piston to move alternately forward and rearward. This leads to the requirement that the inverter output be a spectrally pure sinusoid with zero offset and stable amplitude and frequency. The frequency stability has an additional implication in that the effectiveness of the internal mechanical balancer (vibration absorber) depends on stability of the drive frequency over time and temperature. For that reason, a precise crystal oscillator frequency reference generator is used.

The motor impedance increases, and the thermodynamic efficiency of a Stirling refrigerator decreases, with increasing ambient temperature, hence more input power to the motor is required as the ambient temperature increases. This is accomplished automatically within the electronics by adjusting the amplitude of the alternating voltage to the motor in response to changes in ambient temperature as sensed within the compressor housing.

An output line filter (LC network) is utilized to ensure that high frequency switching EMI is attenuated to comply with the limitations for conducted and radiated EMI permitted by the product specification. Figure 3.3-1

Table 3.2-1. Linear Motor Design Parameters

<u>Overall Dimensions</u>

Outside Diameter of Outer Iron	= 1.71"
Inside Diameter of Inner Iron	= 0.38"
Length	= 1.82"

<u>Outer Iron</u>

Material	2 V Permendur
Outside Diameter	= 1.71"
Length	= 1.82"
Design Max. Flux Density	= 2.4 Tesla

<u>Magnet</u>

Material	Samarium Cobalt Radially Magnetized
Inner Diameter	= 1.25"
Length	= 0.79"

<u>Coil Assembly</u>

Number of Turns/Section	= 90
Outside Diameter	= 1.22"
Inside Diameter	= 0.86"

<u>Inner Iron</u>

Material	2 V Permendur
Inside Diameter	= 0.38"
Length	1.84"
Design Max. Flux Density	= 2.4 Tesla

Table 3.3-1. Electronic Inverter Summary Specifications

- Input 17.0 - 32.0 Vdc
- Internal Helium Temperature -40°C to +100°C
- Output Voltage 10.8V rms, Maximum
- Frequency 54 ± .1%
- Harmonic Distortion $\leq$ 1%
- Efficiency, Maximum

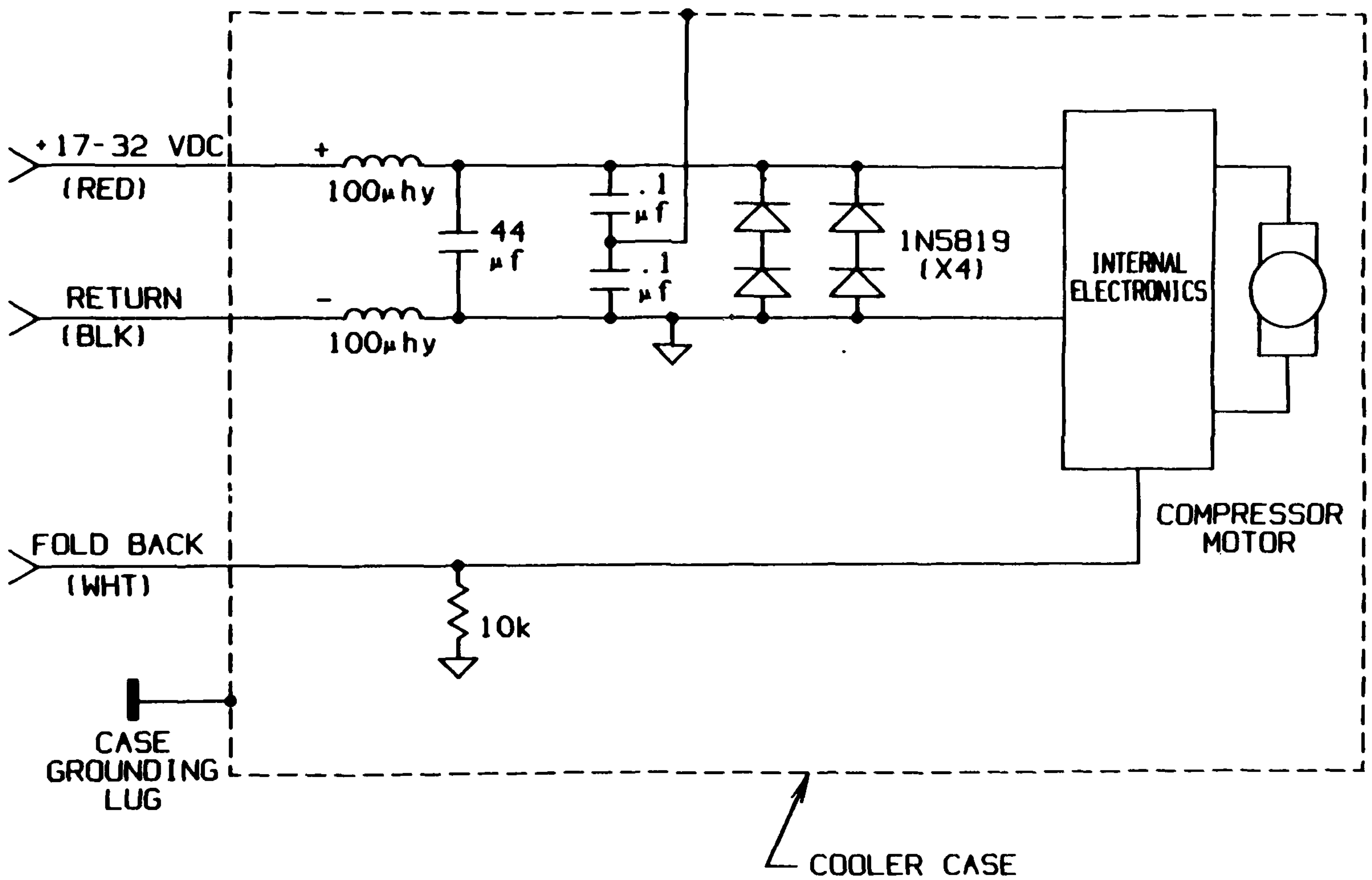

Figure 3.3-1. Line Filter Schematic Diagram

diagramatically illustrates the filter network.

The final configuration of the electronics, then, consists of two hybrid circuits on alumina substrates, and a small discrete component pc board. Figure 3.3-2 is a photograph of the three-board stack.

3.4 VIBRATION ABSORBER

The function of the vibration absorber is to neutralize the shaking force from the moving piston, which would otherwise be transmitted to the compressor housing. The design utilizes a tuned spring/mass system; tuned to the drive frequency. It is located in the compressor, between the linear motor and the electronics (Figure 3.0-2).

For effectiveness, the moving mass must experience as little damping as possible. For low volume, the mass must be of highest density material and maximum outer diameter. When moving during normal operation the mass should not strike any portion of its enclosure. For insurance against particle generation during exposure to vibration and shock environments, the mass should be isolated from the working gas within the cooler.

All of the above are accomplished via the use of a tungsten alloy mass supported by the springs on each of its two sides, the springs operating at all times in compression. The spring/mass system is sealed within an enclosure within the compressor; the enclosure contains filter screen "windows" to permit pressure equalization while retaining any stray metal particles which may be generated during operation.

Figure 3.4-1 is a photograph which illustrates the vibration absorber. The spring which is visible in the photograph is the piston centering spring (Figure 3.0-2).

Figure 3.3-2. Electronics Stack

Figure 3.4-1. Vibration Absorber Assembly

4.0 CONFIRMATORY SAMPLE TEST PROGRAM

As part of this contract six confirmatory sample coolers were fabricated to be subjected to a thorough series of tests. Testing was specified to include full performance testing (cooldown time, cold production, power consumption, operational attitude, gas leakage) and qualification testing (audible noise, vibration output, high temperature, low temperature, temperature shock, vibration, shock, EMI, and reliability/life tests). In addition, physical inspections (size and weight) were performed on each unit. Procedures for the test program are documented in EOSR 1314B, Program Test Plan for Confirmatory Sample Phase Testing, Volumes I and II.

4.1 PURPOSE OF TESTS

In addition to validating Magnavox assembly methods, the test program was undertaken to demonstrate the adequacy of the Magnavox linear resonant cooler design in fulfilling specification performance and configuration requirements.

4.2 DESCRIPTION OF TEST ITEMS

The test lot of six coolers was comprised of serial numbers 10, 11, 13, 15, 16, and 17. Figure 4.2-1, SM-D-5005842, shows the outline configuration of the cooler. Drawing SM-D-5005843 and its sub-tier drawings provide the complete details for the cooler assembly. See Appendix A for drawing SM-D-5005843 and parts list.

4.3 DISPOSITION OF TEST SAMPLES

Disposition of test samples was per contract.

4.4 TEST PERIOD

Testing was initiated with acceptance/performance testing July 16, 1986. Testing was concluded on September 30, 1986.

4.5 LOCATION OF TESTING

All acceptance/performance tests, vibration output, audible noise, and the reliability tests were performed by Magnavox. Environmental tests were performed at CNVEO. EMI tests were performed by CNVEO at White Sands, New Mexico.

4.6 SUMMARY OF RESULTS

4.6.1 MAGNAVOX TESTS

All units complied with the form and weight requirements and all the acceptance/performance requirements. All units complied with the vibration output requirements. Four units were subjected to audible noise testing. All

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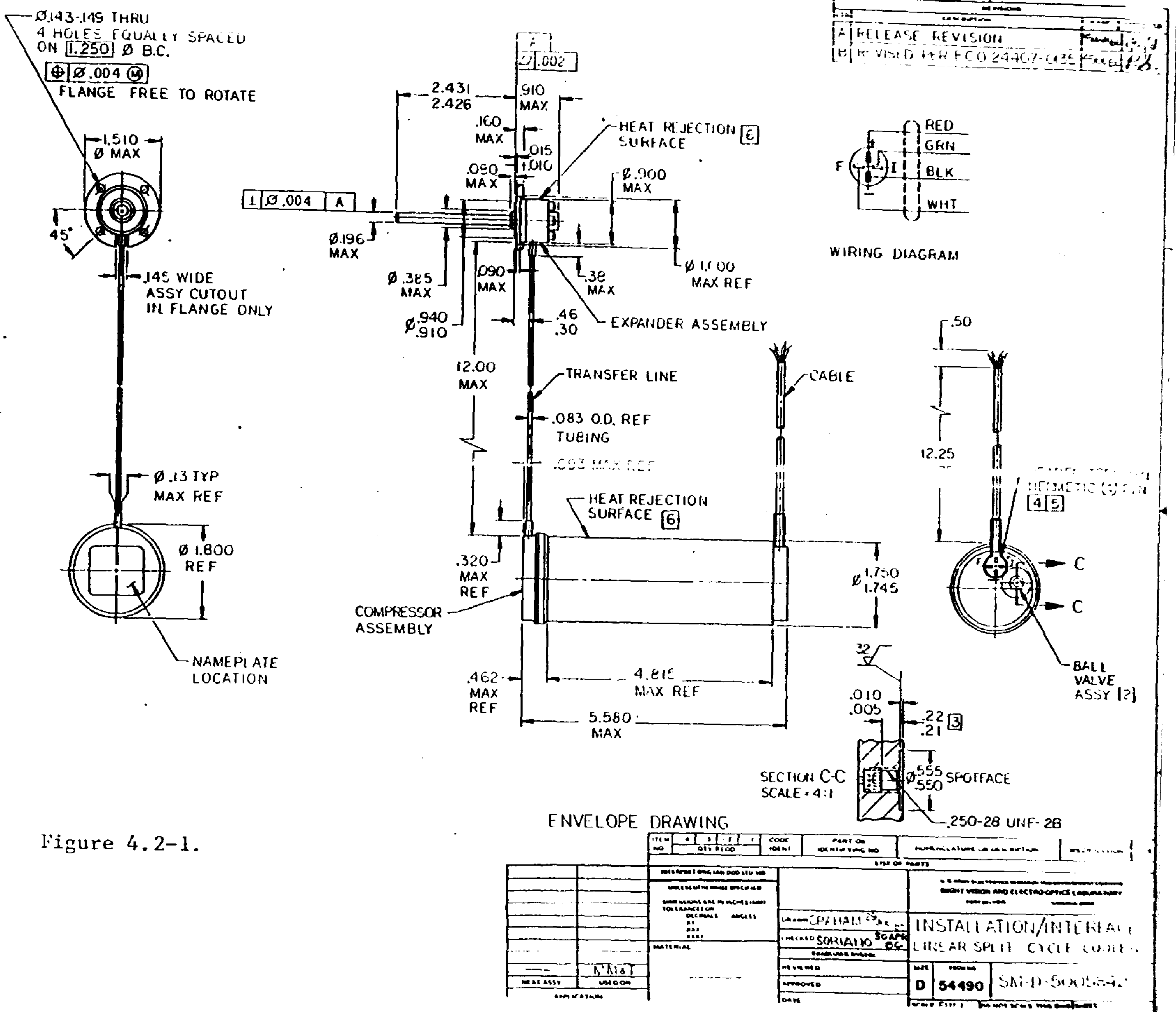


Figure 4.2-1.

units met the requirements for all octave bands except the 5,600-11,200 Hz band. SN 11 exceeded the limit by 2 dB and SN 15 was 7 dB over the limit. Results of the reliability test have provided conclusive evidence that the MM&T Linear Coolers will provide multi-thousand hour operation without service. The average operating hours of the three units in test was 2,545 hours using the Refrigeration Control feature on SN 011.

Detailed test results are described in section 4.7.

4.6.2 CNVEO TESTS

Two units, SN 010 and SN 017, were made available to CNVEO for environmental/EMI testing. Both units were subjected to and met all the requirements of temperature shock, low temperature, high temperature, and mechanical shock. Serial number 010 passed the mechanical vibration test. In the course of vibration testing SN 017, it suffered a nonrelevant failure due to handling. One axis of vibration was successfully completed on SN 017. (Serial number 017 was repaired at Magnavox and returned to CNVEO for additional testing).

Serial number 010 and 017 were EMI tested at White Sands Missile Range. Both units passed the CE-01 tests, Conducted Emissions 30 Hz to 50 kHz, and the RS-03 test, Radiated Susceptibility 14 kHz to 10 GHz. Serial number 010 and 017 exceeded the CE-04 test requirements, Conducted Emissions 50 kHz - 50 MHz, in the range of 15 to 20 MHz by 3 to 10 dB. RE-01, Radiated Emissions, magnetic field, 30 Hz to 30 kHz; requirements were not met at two frequencies, 160 Hz and 223 Hz (2 to 7 dB above limit), both units. During the RE-02, radiated emissions tests, 14 kHz - 10 GHz; levels above the requirement (5 to 10 dB) were found in 25 MHz to 42 MHz range.

Detailed test results for the environmental and EMI tests are presented in paragraph 4.7.3.7.

4.7 DETAILED TEST RESULTS

Three separate categories of tests were required to satisfy the requirements of the contract:

- Inspections (Physical Characteristics)
- Performance Tests
- Qualification Tests

All three categories were addressed successfully in the Confirmatory Sample Test Program.

4.7.1 INSPECTIONS

Each cooler and subassembly was inspected for conformance to the requirements of drawing SM-D-5005842, and SM-D-5005843 and its subtier drawings. All results were recorded and retained in the Quality Control department files. The weight of each cooler was checked for compliance with the requirements of paragraph 3.2.2.2 of the B2 specification. This data is recorded on the acceptance/performance test data sheet for each unit.

4.7.2 ACCEPTANCE/PERFORMANCE TESTS

Prior to being subjected to any of the qualification/environmental tests, each of the coolers was run through a complete series of performance tests in accordance with the approved test plan, EOSR 1314B. These tests included a demonstration of cooler operation in both the horizontal and vertical orientation modes. Vibration output of each cooler was also measured. The acceptance/performance tests were witnessed by a representative of the Government and/or Magnavox Quality Assurance.

4.7.2.1 <u>Acceptance/Performance Test Results</u>

All test results were within specification limits.

4.7.2.2 <u>Data</u>

Acceptance/performance test data, including vibration output for the six coolers is presented at Table 1 of Appendix B. A sample acceptance test data sheet is included as Figures 4.7.2.2-1 and 2 for illustrative purposes.

4.7.3 ENVIRONMENTAL/QUALIFICATION TESTS

For the purposes of this report Acoustic Noise is categorized as an environmental test. The remaining environmental tests were performed at CNVEO, except for EMI which was performed at White Sands Missile Range, New Mexico, under the auspices of CNVEO. Other than the acoustic noise information, all data in this section was provided by CNVEO in their Environmental Test Report dated 9 April 1987.

4.7.3.1 <u>Acoustic Noise</u>

Four coolers were tested for audible noise output in accordance with the requirements of paragraph 3.2.1.5 of the B2 specification. Coolers serial number 11, 13, 15 and 16 were tested for audible noise output. Each of the coolers was tested separately. Each cooler was suspended with rubber bands 60 inches above the floor of the semi-anechoic room. A six foot square piece of 2 inch thick foam was centered on the floor below the cooler to minimize reflection of the generated noise.

Magnavox

ELECTRO-OPTICAL SYSTEMS

Figure 4.7.2.2-1.
Sample Acceptance test Data Sheet (1 of 2)

Sheet 1 of 2

Contract No. DAAK20-84-C-0440 PERFORMANCE TEST

Project No. 24407 DATA SHEET

COOLER, 1/4 WATT LINEAR RESONANT CRYOGENIC SERIAL NO. 010
DRAWING NO. SM-D-5005842

TEST PLAN PARA	PARAMETER	MEASURED	UNITS	LIMITS MIN	MAX
3.10	Calibration Check	COMPLY	-	Comply	
4.1.1	Inspection to SM-D-5005842	COMPLY	-	Comply	
4.1.2	Weight	2.3	Lbs	-	2.5
4.1.3.1	Pressurization	330	PSIG	Info	Only
4.1.3.2	Leakage Rate	1.2×10^{-8}	STP CC/SEC	-	2.7×10^{-7}
4.2.2	Test at 23°C Horiz; Turn-on Current	N/A	Amps	Info	
4.2.2	Cooldown Time to 100°K	4.5	Minutes	-	7.5
4.2.2	Cooldown Time to 80°K	5.3	Minutes	-	10
4.2.2	Minimum Temp	39.5	°K	Info	80
4.2.2.1	Stabl. Temp. with 0.35 Watt Heat Load	65.0	°K		80
4.2.2.2	Temp. after 1/2 Hour Operation	65.8	°K	-	80
4.2.2.3	Cold Finger warm end temp	41.0	°C	Info	Only
4.2.2.4	Input Volt 17 VDC Current 1.42 ADC Power	24.14	Watts	-	30
4.2.2.5	Stabl. Temp with 0.35 Watt Heat Load	65.9	°K		80
4.2.2.5	Cold Finger Warm End Temp	41.0	°C	Info	Only
4.2.2.5	Input Volts 32 VDC Current .84 ADC Power	26.88	Watts	-	30
4.2.3	Test at -40°C Horiz; Turn-on Current	N/A	Amps	Info	
4.2.3.1	Cooldown Time to 100°K	3.9	Minutes	-	7.5
4.2.3.1	Cooldown Time to 80°K	4.6	Minutes	-	10
4.2.3.2	Stabl. Temp with 0.2 Watt Heat Load	45.4	°K	-	80
4.2.3.2	Temp after 1/2 Hour	44.9	°K	-	80
4.2.3.3	Cold Finger Warm End Temp	-28	°C	Info	Only
4.2.3.4	Input Volts 17 VDC Current 1.34 ADC Stablized Power	22.78	Watts	-	30
4.2.3.5	Temp with 0.2 Watt Head Load	45.1	°K	-	80
4.2.3.5	Cold Finger Warm End Temp	-27	°C	Info	Only
4.2.3.5	Input Volts 32 VDC Current .80 ADC Power	25.6	Watts	-	30
4.2.4	Test at 71°C Horiz; Turn-on Current	N/A	Amps	Info	
4.2.4.1	Cooldown Time to 100°K	5.7	Minutes	-	7.5
4.2.4.1	Cooldown Time to 80°K	6.8	Minutes	-	10
4.2.4.1	Stabl. Temp. with 0.2 Watt Heat Load	65.1	°K	-	80
4.2.4.1	Temp after 1/2 hour	66.3	°K	-	80
4.2.4.2	Cold Finger Warm End Temp	87	°C	Info	Only
4.2.4.3	Input Volts 17 VDC Current 1.66 ADC Power	28.22	Watts	-	35
4.2.4.4	Stabl. Temp with 0.2 Watt Head Load	65.6	°K	-	80
4.2.4.4	Cold Finger Warm End Temp	87	°C	Info	Only
4.2.4.4	Input Volts 32 VDC Current ADC .96 Power	30.72	Watts	-	35

Performed By: P. HARTMANN Date: 10-29-86

Witnessed By: [signature] 31 OCT 1986 Q. A. Magnavox

Witnessed By: [signature], DW-QAL Q. A. Customer

Magnavox

ELECTRO-OPTICAL SYSTEMS
P.O. BOX 616, 46 INDUSTRIAL AVENUE, MAHWAH, N.J. 07430-0616
TEL: 201-529-1700 · TWX: 710-988-5672

Figure 4.7.2.2-1.
Sample Acceptance test Data Sheet (2 of 2)

Contract: DAAK20-84-C-0440 PERFORMANCE TEST

Project: 24407 DATA SHEET

COOLER, 1/4 WATT LINEAR RESONANT CRYOGENIC SERIAL NO. 010
DRAWING NO. SM-D-5005842

TEST PLAN PARA	PARAMETER	MEASURED	UNITS	LIMITS MIN	LIMITS MAX
4.2.5	Test at 23°C Vertical; Turn-on Current	N/A	Amps	Info	
4.2.5.1	Cooldown Time to 100°K	4.7	Minutes	-	7.5
4.2.5.1	Cooldown Time to 80°K	5.4	Minutes	-	10
4.2.5.1	Minimum Temp	38.9	°K		80
4.2.5.2	Stabl. Temp with 0.35 Watt Heat Load	66.1	°K	-	80
4.2.5.3	Temp After 1/2 Hour With Heat Load	66.9	°K	Info	80
4.2.5.4	Cold Finger Warm End Temp	34	°C	Info	Only
4.2.5.5	Input Volts 17 VDC Current 1.37 ADC Power ____	23.29	Watts	-	30
4.2.5.6	Stabl. Temp. with 0.35 Watt Heat Load	65.5	°K		80
4.2.5.6	Cold Finger Warm End Temp	35	°C	Info	Only
4.2.5.6	Input Volt 32 VDC Current .82 ADC Power ____	26.24	Watts	-	30
4.2.6	Leakage Rate	2.8×10^{-7}	STP CC/SEC	-	2.7×10^{-7}

PERFORMED BY P. HARTMANN DATE 10-31-86

WITNESSED BY [illegible] Q.A. MAGNAVOX

WITNESSED BY [illegible] Q.A. CUSTOMER

31 OCT 1986

Magnavox

ELECTRO-OPTICAL SYSTEMS

PERFORMANCE TEST

VIBRATION OUTPUT TEST DATA

1/4 WATT LINEAR RESONANT CRYOGENIC COOLER

MM & T PROGRAM

DRAWING NO.: SM-D-5005842 SERIAL NO.: 010

CONTRACT : DAAK20-84-C-0440 PROJECT : 24407

Test Plan Para	Frequency	Maximum Force Along Compressor Axis, ± lbs	Measure Force Along Compressor Axis, lbs.	Maximum Force In Any Compressor Radial Axis, ± lbs	Measured Force In Any compressor Radial Axis, lbs. 0°	90°
4.3.9	Fundamental (54 Hz)	1.0	.529	1.5	.736	1.0
	1st Harmonic (108 Hz)	2.5	2.49	0.22	.024	.22
	2nd Harmonic (162 Hz)	1.4	.776	0.13	.012	.060
	3rd Harmonic (216 Hz)	0.30	.288	0.13	.008	.19
	Next 37 Harmonics	0.10	<.1	0.10	<.1	<.1

PERFORMED BY: *[signature]* DATE: 10/29/86

WITNESSED BY: *[signature]* DCAS-QAR S310A CUSTOMER Q.A. 29 OCT 1986

[signature] MAGNAVOX Q.A.

Figure 4.7.2.2-2. Sample Acceptance Test Data Sheet

In order to simulate operating conditions, the compressors were installed in their heat sinks for this test. Preliminary sound pressure level measurements were made at a distance of one meter from each side of the cooler. From this data, the side of the cooler which emitted the highest sound pressure level was determined. Then, final measurements of the loudest side were taken. As provided for in Test Plan EOSR 1314B, test measurements were taken at a distance of one meter then adjusted to five meters using the following formula:

$$SPL2 = SPL1 - 20 \log D2/D1$$

Where: SPL2 = Sound Pressure level at 5 Meters
SPL1 = Sound Pressure level at 1 Meter
D2 = Specification distance: 5 meters
D1 = Reduced distance: 1 meter

Figures 4.7.3.1-1 and 4.7.3.1-2 are photos of the test setup.

4.7.3.1.1 Results

Coolers SN 13 and 16 complied fully with the specification requirements. Coolers SN 11 and 15 met specification requirements for all octave bands except the 5,600 to 11,200 band. SN 11 output was 22 dB; SN 15 was 27 dB. Specification limit for this band is 20 dB.

Summarized Audible Noise Results

		Maximum Sound Pressure Level Measured			
Octave Band Center Freq.	Spec. Level	Cooler SN 011	Cooler SN 013	Cooler SN 015	Cooler SN016
125	37	16	16	16	22
250	30	6	6	6	9
500	30	5	8	20	9
1,000	25	7	13	21	6
2,000	20	7	11	17	4
4,000	20	13	13	18	6
8,000	20	22	16	27	13

4.7.3.1.2 Data

Sound pressure levels for each cooler over the octave bands is shown in Table 1, Tab 2 of Appendix B. This table presents a tabulation of the data and plots of the specificaion limit and of the maximum audible noise levels at the specified 5 meters distance.

4.7.3.2 Temperature Shock Test (CNVEO)

The temperature shock test was performed according to MIL-STD-810C, Method 503.1, Procedure 1. The test consisted of placing the cooler in a temperature chamber with temperature of 71°C for four hours. At the end of the four hour heat soak the cooler was transferred to a cold temperature chamber with a temperature of -54°C for another four hours. This process was cyclically repeated for twenty-four hours. The transfer time between the hot and cold

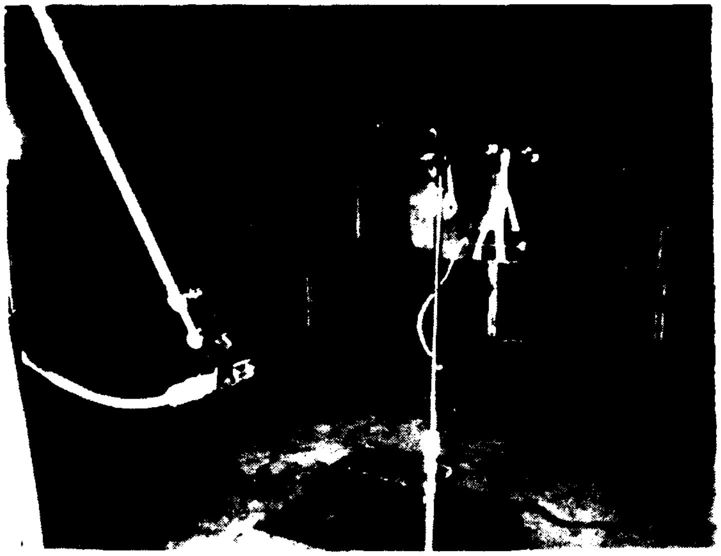


Figure 4.7.3.1-1. MM&T Cooler Acoustic Noise Test Set Up

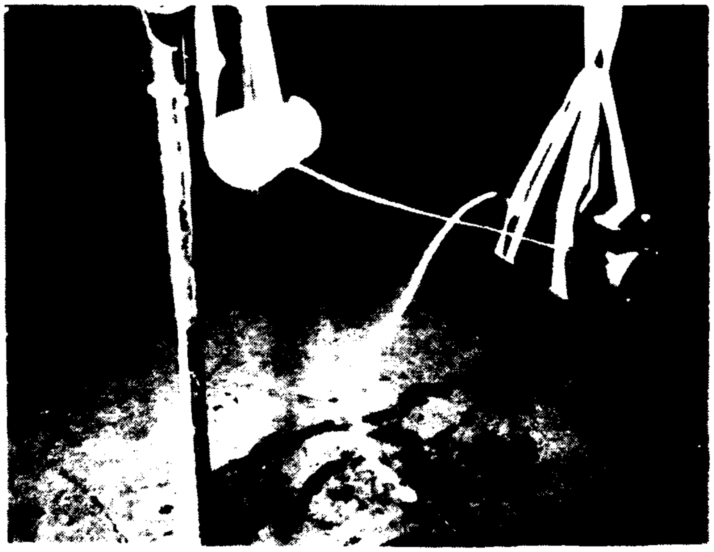


Figure 4.7.3.1-2. MM&T Cooler Acoustic Noise Test Set Up

temperature chambers did not exceed five minutes. The parameters of the test are documented in tables 4.7.3.2-1 and 4.7.3.2-2.

4.7.3.2.1 Results

Both coolers SN010 and SN017 passed the temperature shock test and the ensuing acceptance tests. Details may be found in the tables, following Tab 3 of Appendix B.

4.7.3.2.2 Data

Pretemperature shock and post temperature shock data is shown following Tab 3 of Appendix B.

4.7.3.3 Low Temperature Test

The low temperature test was performed in accordance with MIL-STD-810C, Method 502.1, Procedure I. The test consisted of placing the cooler in a temperature chamber with a temperature of -57°C for twenty-four hours. Then the chamber's temperature was raised, and when it stabilized at -40°C, the cooler was subjected to a baseline performance test. The temperatures of the cold soak and operation phases are documented in Figure 4.7.3.3-1 and tables 4.7.3.3-1 and 4.7.3.3-2.

4.7.3.3.1 Results

Both coolers, SN010 and SN017 passed the low temperature test and the ensuing acceptance test.

4.7.3.3.2 Data

Low temperature test data may be found following Tab 4 of Appendix B.

4.7.3.4 High Temperature Test (CNVEO)

Conditions: The high temperature test was performed in accordance with MIL-STD-810C, Method 501.1, Procedure I. The test consisted of placing the cooler in a temperature chamber with a temperature of 71°C for 48 hours. At the end of that period, a baseline test was performed with the cooler at 71°C ambient temperature. The temperature of the heat soak and the operation phase are documented in Figure 4.7.3.4-1 and tables 4.7.3.4-1 and 4.7.3.4-2.

4.7.3.4.1 Results

Both coolers, SN010 and SN017, passed the high temp. test and the ensuing acceptance test.

4.7.3.4.2 Data

Tab 5 of Appendix B presents the high temperature test data.

Table 4.7.3.2-1

PERFORMANCE TEST DATA SHEET

Cooler, 1/4 Watt Linear Resonant Cryogenic
MM&T Program
Temperature Shock Test
S/N : 010
Date of Test : 25-26 NOV 86
Tested by : HLD / HEC

Parameter	Start	End	Pass	Fail	Comply
Pre-test operation			✓		
4 Hours @ +71 C	25 NOV 06:20	10:20			✓
4 Hours @ -54 C	10:20	14:20			✓
4 Hours @ +71 C	14:20	18:20			✓
4 Hours @ -54 C	18:20	22:20			✓
4 Hours @ +71 C	22:20	26 NOV 02:20			✓
4 Hours @ -54 C	02:20	06:30			✓
Stabilize @ +23 C	06:30	11:45			✓
Operation @ +23 C	11:45	12:25	✓		

Table 4.7.3.2-2

PERFORMANCE TEST DATA SHEET

Cooler, 1/4 Watt Linear Resonant Cryogenic
MM&T Program
Temperature Shock Test
S/N : 017
Date of Test : 25-26 NOV 86
Tested by : HLD / HEC

Parameter	Start	End	Pass	Fail	Comply
Pre-test operation			✓		
4 Hours @ +71 C	25 NOV 06:20	10:20			✓
4 Hours @ -54 C	10:20	14:20			✓
4 Hours @ +71 C	14:20	18:20			✓
4 Hours @ -54 C	18:20	22:20			✓
4 Hours @ +71 C	22:20	26 NOV 02:20			✓
4 Hours @ -54 C	02:20	06:20			✓
Stabilize @ +23 C	06:20	11:45			✓
Operation @ +23 C	11:45	12:25	✓		

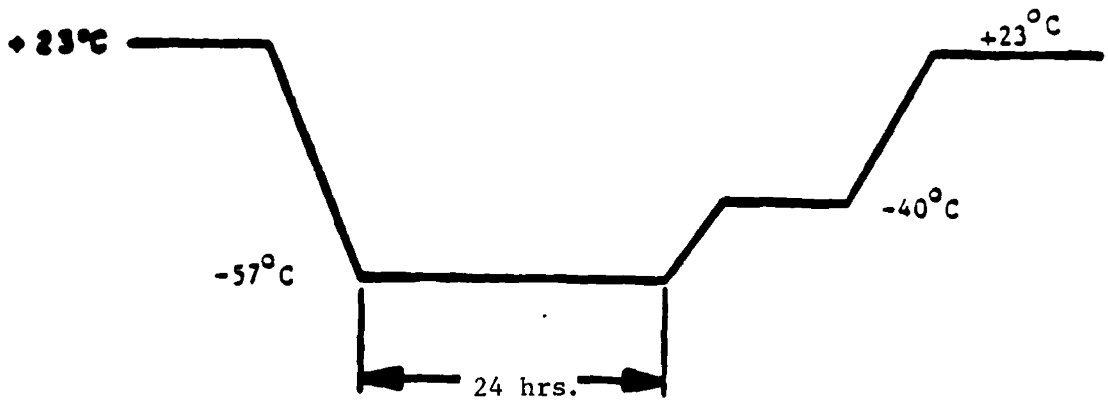


Figure 4.7.3.3-1. Low Temperature Test Profile

Table 4.7.3.3-1

PERFORMANCE TEST DATA SHEET

Cooler, 1/4 Watt Linear Resonant Cryogenic
MM&T Program
Low Temperature Test
S/N : 010
Date of Test : 8-10 DEC 86
Tested by : HLD

Parameter	Start	End	Pass	Fail	Comply
Pre-test operation			✓		
24 Hour Soak @ -57 C	8 DEC 11:35	9 DEC 11:35			✓
Raise Temp to -40 C	11:35	12:30			✓
Stabilize @ -40 C .5 Hr	12:30	13:15			✓
Operation @ -40 C	13:15	13:55	✓		
Post-test Performance	10 DEC 10:13	10 DEC 10:53	✓		

Table 4.7.3.3-2

PERFORMANCE TEST DATA SHEET

Cooler, 1/4 Watt Linear Resonant Cryogenic
MM&T Program
Low Temperature Test
S/N : 017
Date of Test : 12-15 DEC 86
Tested by : HLD

Parameter	Start	End	Pass	Fail	Comply
Pre-test operation			✓		
24 Hour Soak @ -57 C	12 DEC 07:55	13 DEC 07:55			✓
Raise Temp to -40 C	07:55	08:30			✓
Stabilize @ -40 C .5 Hr	08:30	09:15			✓
Operation @ -40 C	09:15	09:55	✓		
Post-test Performance	15 DEC 10:35	15 DEC 11:15	✓		

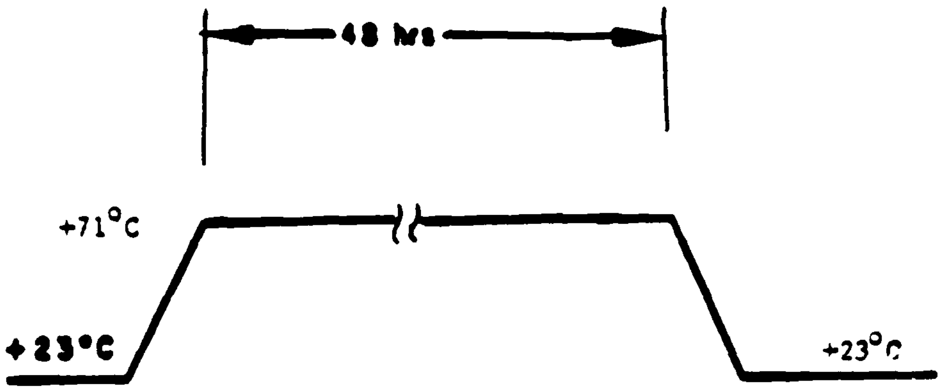


Figure 4.7.3.4-1. High Temperture Test Profile

Table 4.7.3.4-1

PERFORMANCE TEST DATA SHEET

Cooler, 1/4 Watt Linear Resonant Cryogenic
MM&T Program
High Temperature Test
S/N : 010
Date of Test : 5-7 DEC 86
Tested by : HGK/HEC

Parameter	Start	End	Pass	Fail	Comply
Pre-test operation			✓		
48 Hour Soak @ +71 C	5 DEC 15:45	7 DEC 15:45			✓
Operation @ +71 C	7 DEC 16:00	7 DEC 16:40	✓		
Post-test Performance			✓		

Table 4.7.3.4-2

PERFORMANCE TEST DATA SHEET

Cooler, 1/4 Watt Linear Resonant Cryogenic
MM&T Program
High Temperature Test
S/N : 017
Date of Test : 1-5 DEC 86
Tested by : HGK/HEC

Parameter	Start	End	Pass	Fail	Comply
Pre-test operation			✓		
48 Hour Soak @ +71 C	1 DEC 11:15	3 DEC 12:30			✓
Operation @ +71 C	5 DEC 12:45	13:25	✓		
Post-test Performance			✓		

4.7.3.5 Mechanical Shock Test

The mechanical shock test was performed in accordance with MIL-STD-810C, Method 516.2, Procedure IV. The test consisted of subjecting the cooler to a specified shock pulse which was established using a dummy load. Two shock pulses in both directions were applied along the cooler's three axis, totalling twelve pulses. Details may be found in Figure 4.7.3.5-1 and tables 4.7.3.5-1 and 4.7.3.5-2.

4.7.3.5.1 Results

Both coolers, SN010 and SN017 passed the mechanical shock test and the ensuing acceptance test.

4.7.3.5.2 Data

Post mechanical shock performance data may be found at Tab 6 of Appendix B.

4.7.3.6 Mechanical Vibration

Conditions. The Mechanical Vibration test was performed in accordance with MIL-STD-810C, Method 514.2, Procedure I cycle time 120 min. per axis, dwell time 1/6 cycling of each resonance. The test consisted of vibrating the cooler in a swept sine wave vibration on each of the 3 axis. See figure 4.7.3.6-1.

4.7.3.6.1 Results

Cooler SN010 passed the mechanical vibration test and the ensuing acceptance test. A non relevant failure due to excessive handling occurred during testing of cooler SN017. Details may be fund in Figure 4.7.3.6-2 and table 4.7.3.6-1.

4.7.3.6.2 Data

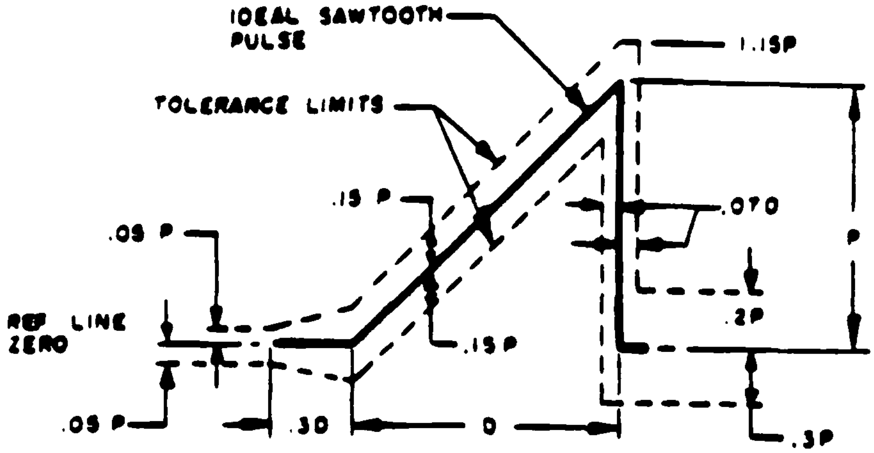
Post vibration test data for SN10 may be found at Tab 7 of Appendix B.

4.7.3.7 EMI Testing

EMI tests were performed as described in Magnavox Test Plan EOSR 1328A Volume II, dated 29 Jan. 86. The tests were performed at the Electromagntic Radiation Effect Test Facility, White Sands Missile Range, NM during the period of 24 Feb. through 2 Mar. 87.

4.7.3.7.1 Results

Coolers SN 010 and cooler SN 017 satisfied the test requirements with two exceptions. For details consult Exhibit 1.



PROCEDURE	TEST	PEAK VALUE (P) g's		NOMINAL DURATION (D) ms	
		FLIGHT VEHICLE EQUIPMENT a 1/	GROUND EQUIPMENT b	FLIGHT VEHICLE EQUIPMENT c 1/	GROUND EQUIPMENT d
I	BASIC DESIGN	20	40 2/	11	11
III	CRASH SAFETY	40	75	11	6
IV	HIGH INTENSITY	100	100	6	11

1/ SHOCK PARAMETERS a AND c: RECOMMENDED FOR EQUIPMENT NOT SHOCK MOUNTED AND WEIGHING LESS THAN 300 POUNDS.

2/ EQUIPMENT MOUNTED ONLY IN TRUCKS AND SEMITRAILERS MAY USE A 20g PEAK VALUE.

NOTE: THE OSCILLOGRAM SHALL INCLUDE A TIME ABOUT 3D LONG WITH A PULSE LOCATED APPROXIMATELY IN THE CENTER. THE PEAK ACCELERATION MAGNITUDE OF THE SAWTOOTH PULSE IS P AND ITS DURATION IS D. THE MEASURED ACCELERATION PULSE SHALL BE CONTAINED BETWEEN THE BROKEN LINE BOUNDARIES AND THE MEASURED VELOCITY CHANGE (WHICH MAY BE OBTAINED BY INTEGRATION OF THE ACCELERATION PULSE) SHALL BE WITHIN THE LIMITS OF $V_i \pm 0.1\ V_i$, WHERE V_i IS THE VELOCITY-CHANGE ASSOCIATED WITH THE IDEAL PULSE WHICH EQUALS 0.5 DP. THE INTEGRATION TO DETERMINE VELOCITY CHANGE SHALL EXTEND FROM 0.4D BEFORE THE PULSE TO 0.1D AFTER THE PULSE.

Figure 4.7.3.5-1. Terminal-peak Sawtooth Shock Pulse Configuration and Its Tolerance Limits

Table 4.7.3.5-1

PERFORMANCE TEST DATA SHEET

Cooler, 1/4 Watt Linear Resonant Cryogenic
MM&T Program
Mechanical Shock Test
S/N : Ø1Ø
Date of Test : 16 Dec 86
Tested by : H Kling

Parameter	Start	End	Pass	Fail	Comply
Pre-test operation			✓		
12 Shocks Total					✓
Post-test Performance			✓		
Leak Test			✓		

Table 4.7.3.5-2

PERFORMANCE TEST DATA SHEET

Cooler, 1/4 Watt Linear Resonant Cryogenic
MM&T Program
Mechanical Shock Test
S/N : Ø17
Date of Test : 16 Dec 86
Tested by : H. Klines

Parameter	Start	End	Pass	Fail	Comply
Pre-test operation			✓		
12 Shocks Total					✓
Post-test Performance			✓		
Leak Test			✓		

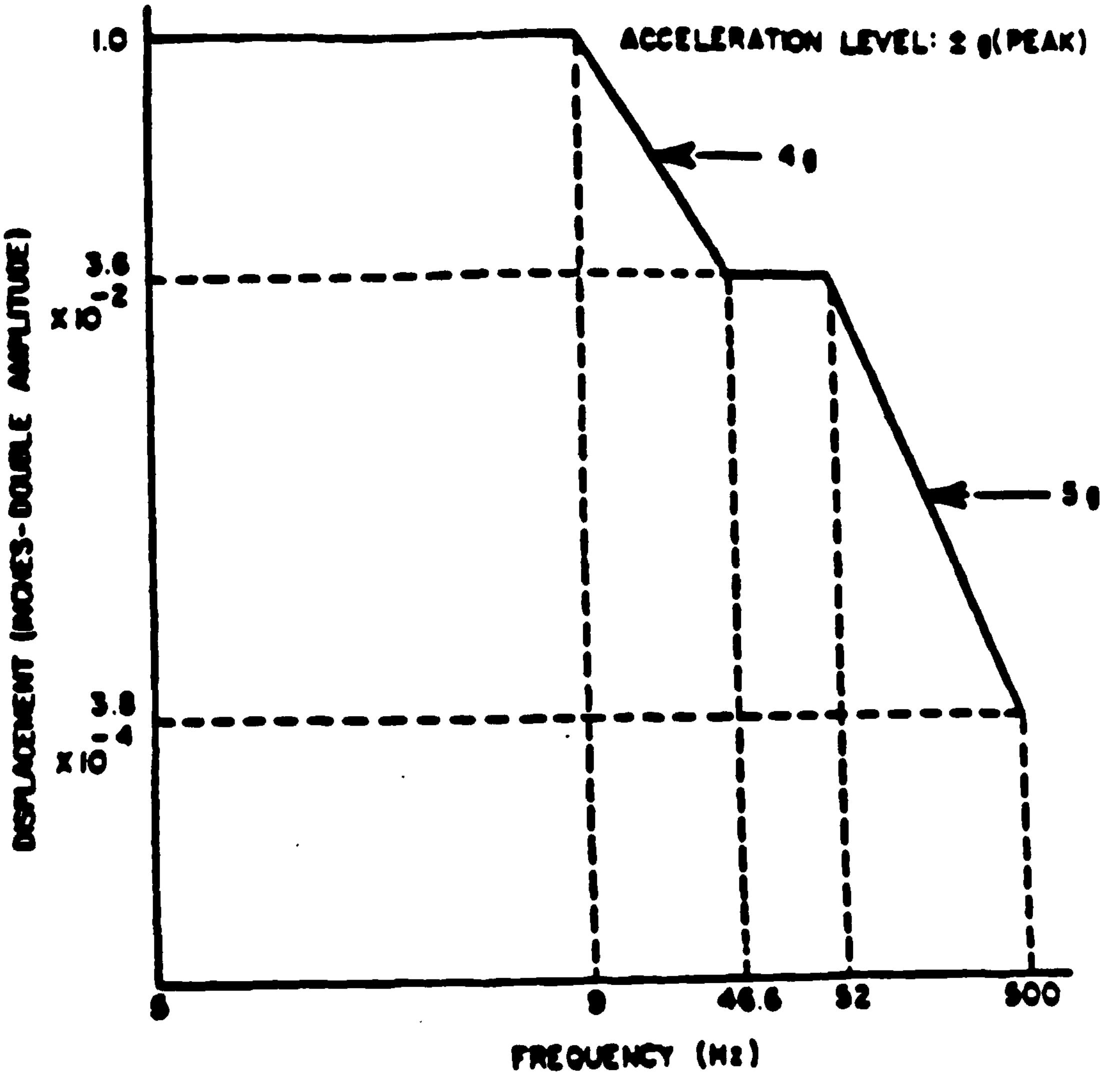


Figure 4.7.3.6-1. Vibration Test Profile

Figure 4.7.3.6-2
Mechanical Vibration Test Results

TEST ITEMS

Linear Resonant Coolers, Magnavox S/N 010 and 017.

TEST DESCRIPTION

Swept Sine Vibration, page 19 of Figure 6, Linear Resonant Cooler, MM&T Test Plan, April 18, 1986 Revision.

TEST RESULTS

Cooler #010 remained operating and its coldfinger remained frosted during all vibration cycling on all three axes.

Cooler #017 stopped operating after completing only the X axis. The failure occurred while the cooler fixture was being rotated to perform Z axis vibration. There was loud internal clattering for approximately 5 seconds followed by hissing and defrosting. Testing of unit 017 was terminated at this time.

Both units were returned to Mr. Henry Kling for further evaluation.

There were no resonance searches or dwells performed per verbal instructions from Mr. Kling.

David J. Allingham

DAVID J. ALLINGHAM
Test Coordinator
Support Operations Team
Technical Support Division
Center for Night Vision and Electro-Optics

Table 4.7.3.6-1

PERFORMANCE TEST
DATA SHEET

COOLER, 1/4 WATT LINEAR RESONANT CRYOGENIC SERIAL NO. SN 010
MM&T PROGRAM

DRAWING NO.________ TESTED BY David Allingham APPROVED BY________

TEST PLAN PARA	PARAMETER	MEASURED	UNITS	LIMITS MIN	LIMITS MAX	DATE OF TEST
4.3.2	Vibration					
4.3.2.1	Pre Test Operation	✓	Frost on C.F.	Comply	-	06 Jan 87
	Input Power	✓	Watts	-	30	"
	Vibration Along Motor Longitudinal Axis Z Axis	✓	-	Comply	-	"
	Vibration Along Motor Transfer Y Axis	✓	-	Comply	-	"
	Vibration Perpendicular to Transfer Tube Axis X Axis	✓	-	Comply		"
	Post Operation Test	✓		Comply	-	07 Jan 87
	Input Power	✓	Watts	-	30	

C.F. = Cold Finger

4.7.3.7.2 Data

EMI test data may be found at Tab 8 of Appendix B.

4.7.4 RELIABILITY TEST

A key element of the Confirmatory Sample Test Program was the reliability test. Three units were subjected to temperature and operational cycling in accordance paragraph 4.2.3 of the Purchase Description. Prior to being placed into reliability testing, each of the coolers was subjected to a complete acceptance test.

The purpose of the reliability test was to demonstrate a mean time to failure (MTTF) of 2,500 hours. MTTF defined as total cooler hours divided by total failures.

Failure criteria was established as cooling capacity degradation of greater than 20% of the specification heat load requirement with 80°K or less cold finger temperature.

4.7.4.1 Test Conditions

Cooler reliability testing was performed with the coolers set up in an environmental chamber, as shown schematically in Figure 4.7.4.1-1. The coolers were operated and cycled through temperatures of -32°C, 23°C and 52°C in a twenty-four hour period in accordance with the following schedule:

The coolers were set up for operation at 17.5 Vdc, turned on at 23°C; cooldown time was measured. After 10 minutes from turn-on, a .350 watt heat load* was applied. The chamber was maintained at 23°C for 3 hours from the start point. Then, with the coolers operating with heat load, the chamber temperature was lowered to -32°C in 2 hours. The .350 watt heat load* was maintained and the coolers were operated for 1 hour at -32°C. Chamber temperature was then raised to 52°C in three hours, with coolers running and heat load applied. The coolers were operated at 52°C for 1 hour with a .290 watt heat load*. Chamber temperature was then returned to 23°C; coolers operating, heat load applied. Operation at 23°C with a .350 watt heat load was maintained for 9 hours. At the completion of the 9 hours, coolers and heat loads were turned off, chamber temperature was maintained at 23°C for 4 hours to complete the 24 hour cycle. The test profile is shown in Figure 4.7.4.1-2.

---

* Heat loads were not derated to the allowed 80% during the first 3,500 hours of the reliability test. All heat loads were full specification requirement. At -32°C, Magnavox chose to use the higher heat load of .350 watts rather than the allowed lower value of .260 watts.

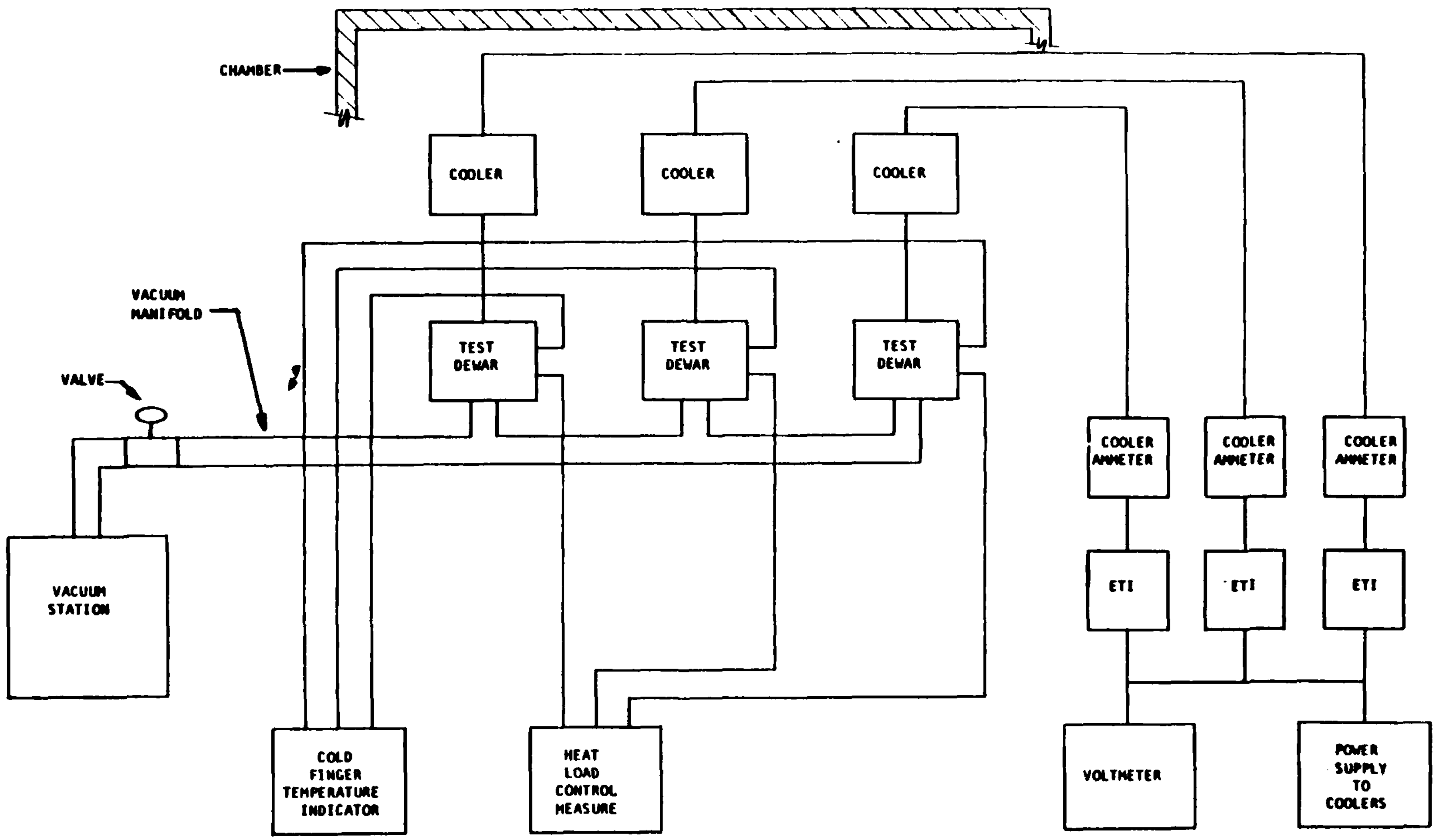
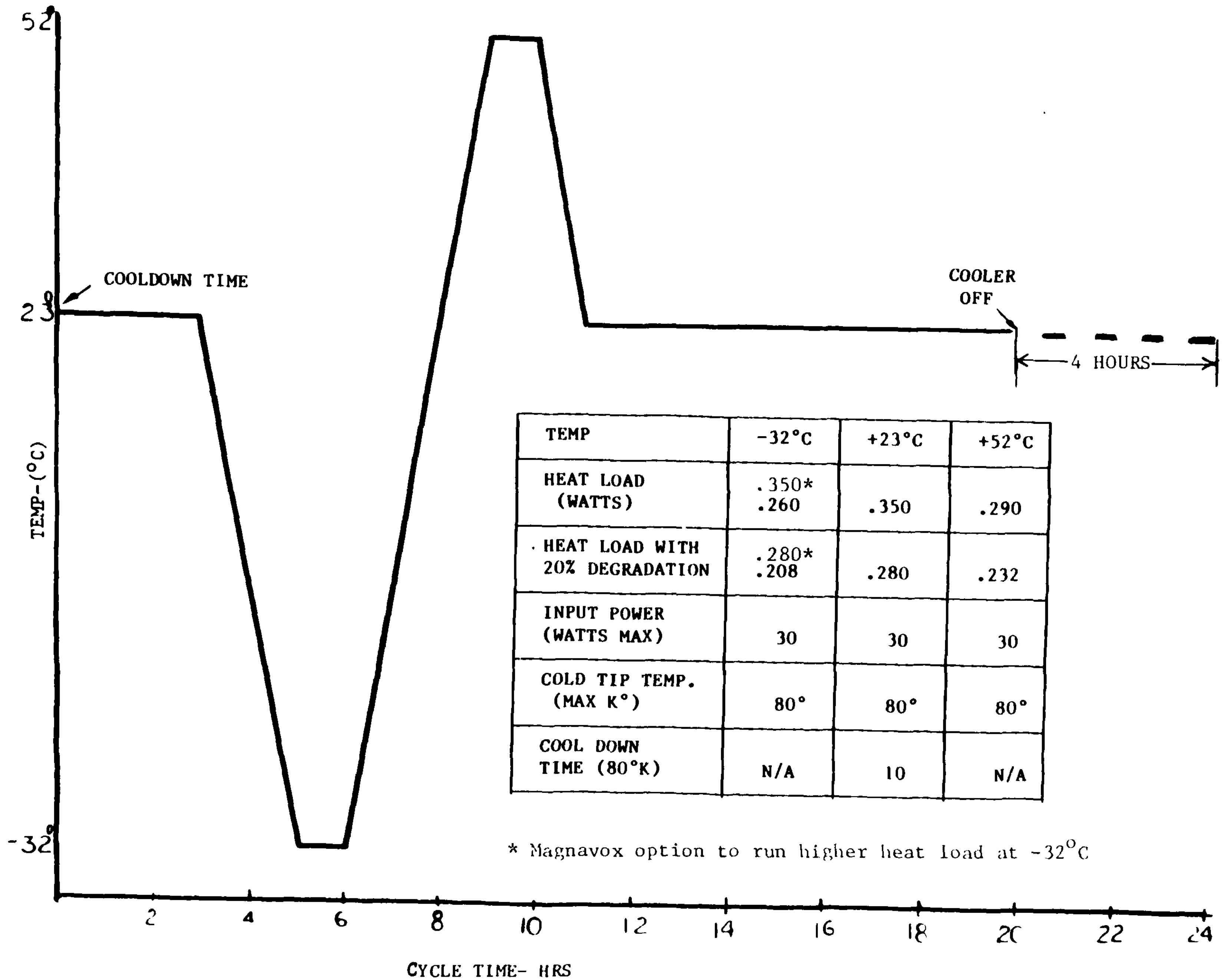


Figure 4.7.4.1-1. Test Setup



TEMP	-32°C	+23°C	+52°C
HEAT LOAD (WATTS)	.350* .260	.350	.290
HEAT LOAD WITH 20% DEGRADATION	.280* .208	.280	.232
INPUT POWER (WATTS MAX)	30	30	30
COLD TIP TEMP. (MAX K°)	80°	80°	80°
COOL DOWN TIME (80°K)	N/A	10	N/A

* Magnavox option to run higher heat load at -32°C

Figure 4.7.4.1-2. Test Profile

At least once every 24 hours the following measurements were made on each of the coolers:

- Cold finger temperature
- Heat load
- Cooler power consumption
- Elapsed time indicator reading

Reliability testing was initiated September 15, 1986, and concluded September 30, 1987.

4.7.4.2 Reliability Test Summary

Three units were used for the reliability test; serial numbers 11, 15, and 16. Serial number 15 was placed on test September 15, 1986 and ran for 1,622 hours within specification limits, using full rated heat load. It was removed from test on December 8, 1986 when a shrill rapping noise was heard. Investigation revealed failure of the Piston Spool threads which engage the centering spring (PN SM-C-5005878). As corrective action, the Piston Spool was redesigned; the material was changed from 304 stainless to 17-4 PH steel, Spool/Spring engagement length was increased, and the thread post radius was increased. Details of this failure may be found in Failure Report 24407-004 in Appendix C.

Serial number 16 reliability testing was started October 30, 1986. The unit was installed in the test chamber with SN 15. At approximately 160 hours of operation it was noted that the input power was 30.1 watts at 52°C ambient temperature. After a review of the condition and data relating to SN 016 it was concluded that the over limit reading was not due to a design malfunction, but rather a marginal setting of the internal adjustment of the cold production/power consumption balance. Accordingly, the concensus was that this not be considered a chargeable failure and SN 16 was continued in the reliability test. Failure Report 24407-003 in Appendix C provides the details of this event. Serial number 16 continued to operate within specification limits for a total of 1,418 hours. In hour 1,419, at -32°C ambient, it was observed that cooler input current had dropped to .1 amperes and cold finger temperature was 380°K. The cooler was essentially shut down. After removal from the chamber, the malfunction was confirmed in the cryogenics test lab. Exhaustive investigation and testing revealed the problem was not only temperature sensitive, but also mechanical shock could trigger the fault. Further testing revealed the problem to be an unbonded lead on the inverter hybrid, in the electronics assembly. With the repair of the unbonded lead, and two others which appeared marginal, the cooler was subjected to several temperature cycles with no further problems. Refer to Failure Report 24407-005 in Appendix C, for further details. Reliability testing was not resumed.

Cooler serial number 11, began reliability tests September 15, 1986. After approximately 217 hours of operation, the cooler was removed from the reliability test on September 26, 1986. The reason for removal was an uncharacteristic early degradation of performance. Cold finger temperature was 81.6°K at -32°C ambient and a .350 watt heat load. Reducing the heat load to the allowed 80% value of .280 watts resulted in a cold finger temperature of 72.5°K at 23°C ambient. Although neither reading was beyond specification limit, this type of performance was not typical of our coolers. Accordingly, SN 11 was removed from the reliability test on September 26, 1986 after 217 hours of operation. The cooler was subjected to an intensive series of inspections, analyses, and tests to determine the cause of this anomoly. Three separate factors were established as contributing to the degradation of cold production of SN 11:

a) Gas contamination

b) Partial contamination of the regenerator

c) Poor regenerator rulon/cold finger fit

For complete details of the gas analysis, regenerator contamination, and the rulon/cold finger fit, refer to Failure Report 24407-002 in Appendix C.

None of the foregoing items being related to a design deficiency, cooler SN 11 was returned to the reliability test on October 24, 1986. The reliability test clock was reset to zèro hours. The cooler provided in-spec operation for approximately 2,500 hours at -32°C and 23°C. At 2,500 hours the input power was 30.1 watts at -32°C, and 30.3 watts at 23°C. The input power at 52°C was 30.1 watts at 1210 hours. This was discussed with CNVEO representatives, and with their concurrence, the test continued. (The marginal power condition is the result of an assembly/test adjustment which balances power consumption versus cold production.) The cooler was operating in full cooling mode, not using the fold-back (refrigeration control mode). The cooler continued to run in full cooling mode, maintaining less than 80°K cold station temperture, with the life test heat load. (For plots of the data, and heat loads used, see Figures 2 through 4.) Input power increased to a maximum of 35.9 watts (52°C plateau) at 4550 hours. At 4596 hours, using the refrigeration control mode, the cooler was brought to virtual specification performance. Table 4.7.4.2.1 contains the data taken at 4596 hours. Testing of SN 11 continued. Beyond 4600 hours, cold finger temperature and power rose steadily and could not be brought into spec with the fold-back (refrigeration control) circuit. It was decided, with CNVEO concurrence, to run the cooler beyond this point for informational purposes. On September 30, 1987 after 6435 hours of operation, the cold finger temperature had risen to 111°K and the input power to the cooler was 50.8 watts, at -32°C ambient. The cooler had been operating with the specified heat load of .280 watts. It was felt any further operation of the cooler would not provide additional useful data. At 6500 hours the test was stopped and an analysis was performed.

The analysis revealed the degradation in performance was due solely to an increase in the compressor piston seal clearance gap, due to wear of the piston rulon sealing surface. Failure report 24407-006 in Appendix C details the results of this analysis.

4.7.4.3 Reliability Test Results

The failures of S/N 15 and 16 were in the former case due to a design deficiency subsequently corrected, and in the latter case due to a quality problem on the preproduction vintage hybrid circuits. The long, trouble-free performance of S/N 11 is therefore more typical of the coolers.

- SN 15: Using stainless steel as the spring keeper material was an oversight. The opposite end spring keeper material was made of 17-4 PH. No recurrence of this failure.
- SN 16: Failed as a result of a process control not up to production quality standards. No recurrence of this failure.
- SN 11: Provided the benchmark performance, with 4,600 hours of in spec operation at -32°C and 23°C, and less than 10% beyond the input power limit at 52°C. This type of performance removes from the coolers, the stigma of the system life-limiting component. After removal from test at 6,500 hours, the only component replacement needed was a new piston assembly, PN SM-C-5005853. With a new piston installed, the cooler met acceptance test requirements.
- The results were particularly significant in that they provide an insight to the refurbishment philosophy applicable to the Magnavox long-life linear cooler.

Cooldown Time to 100 K 6.8 min.
" " " " 85 K 7.6 min.

	VDC	I	WATTS	FBV	°K	H.L.
20°C	17.5	1.98	34.65	0.0	79.5	.350
	17.5	1.96	34.30	1.96	80.4	.350
	17.5	1.72	30.10	3.19	80.0	.280
	17.5	2.02	35.35	0.0	71.5	.280
-32°C	17.5	1.96	34.30	0.0	80.5	.350
	17.5	----	-----	---	----	.350
	17.5	1.66	29.05	3.29	80.5	.280
	17.5	1.98	34.65	0.0	68.7	.280
52°C	17.5	2.05	35.88	0.0	82.5	.290
	17.5	----	-----	---	----	.290
	17.5	1.88	32.90	3.05	80.2	.232
	17.5	2.07	36.23	0.0	75.7	.232

Table 4.7.4.2-1. Foldback/Input Power Unit S/N 001

The MM&T reliability test results demonstrate the ability of the Magnavox linear coolers to provide multi-thousand hour service-free operation. No inherent long term design deficiences were encountered.

4.7.4.4 Reliability Test Data

Figures 4.7.4.4-1 through 4.7.4.4-9 are plots of the reliability test performance of coolers SN 11, SN 15 and SN 16 at ambient temperatures of -32°C, 23°C and 52°C. Tabulated data is presented in Appendix B, Tab 9 for SN 11, Tab 10 for SN 15, and Tab 11 for SN 16.

Figure 4.7.4.4-1.

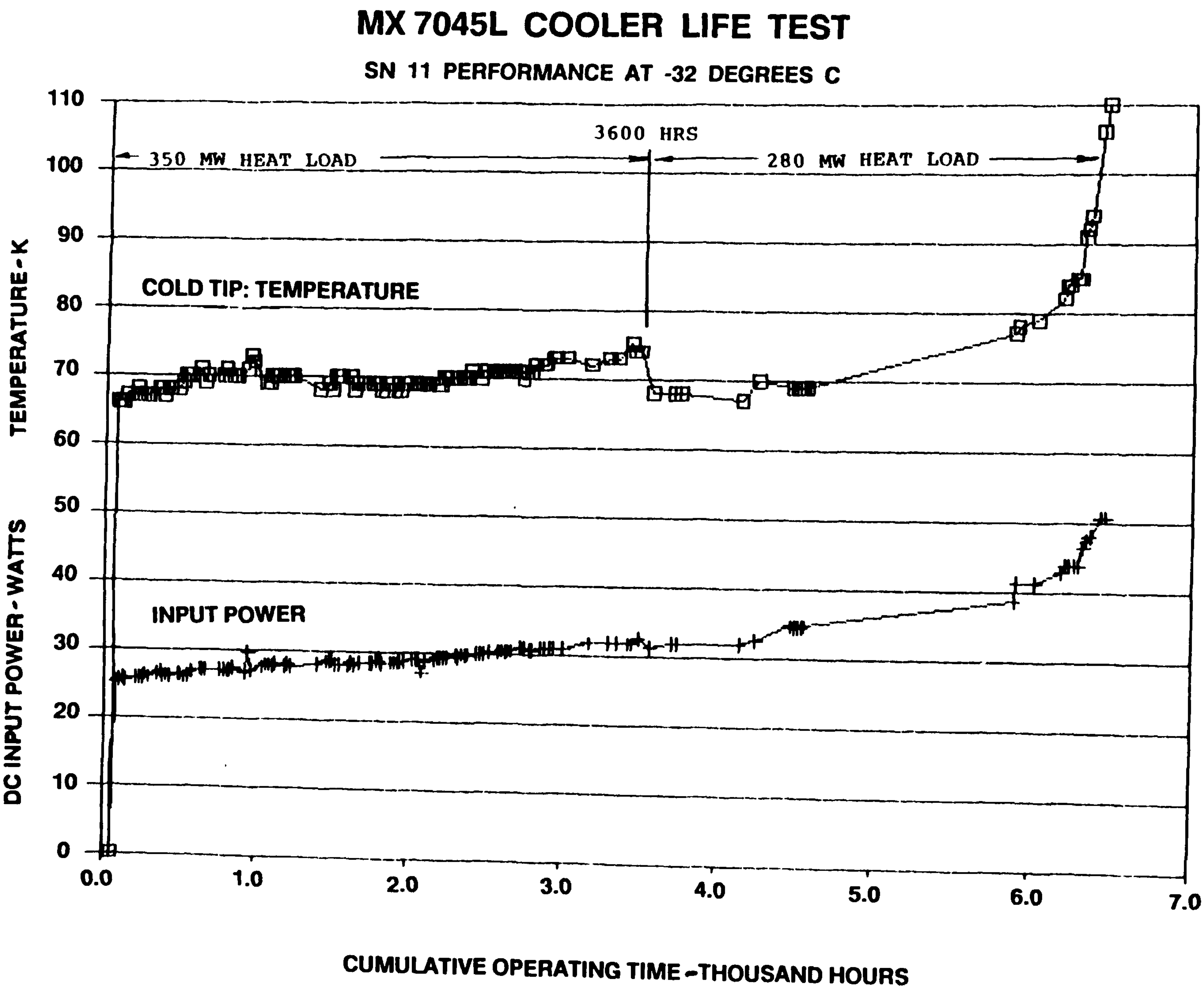


Figure 4.7.4.4-2.

MX 7045L COOLER LIFE TEST

SN 11 PERFORMANCE AT 23 DEGREES C

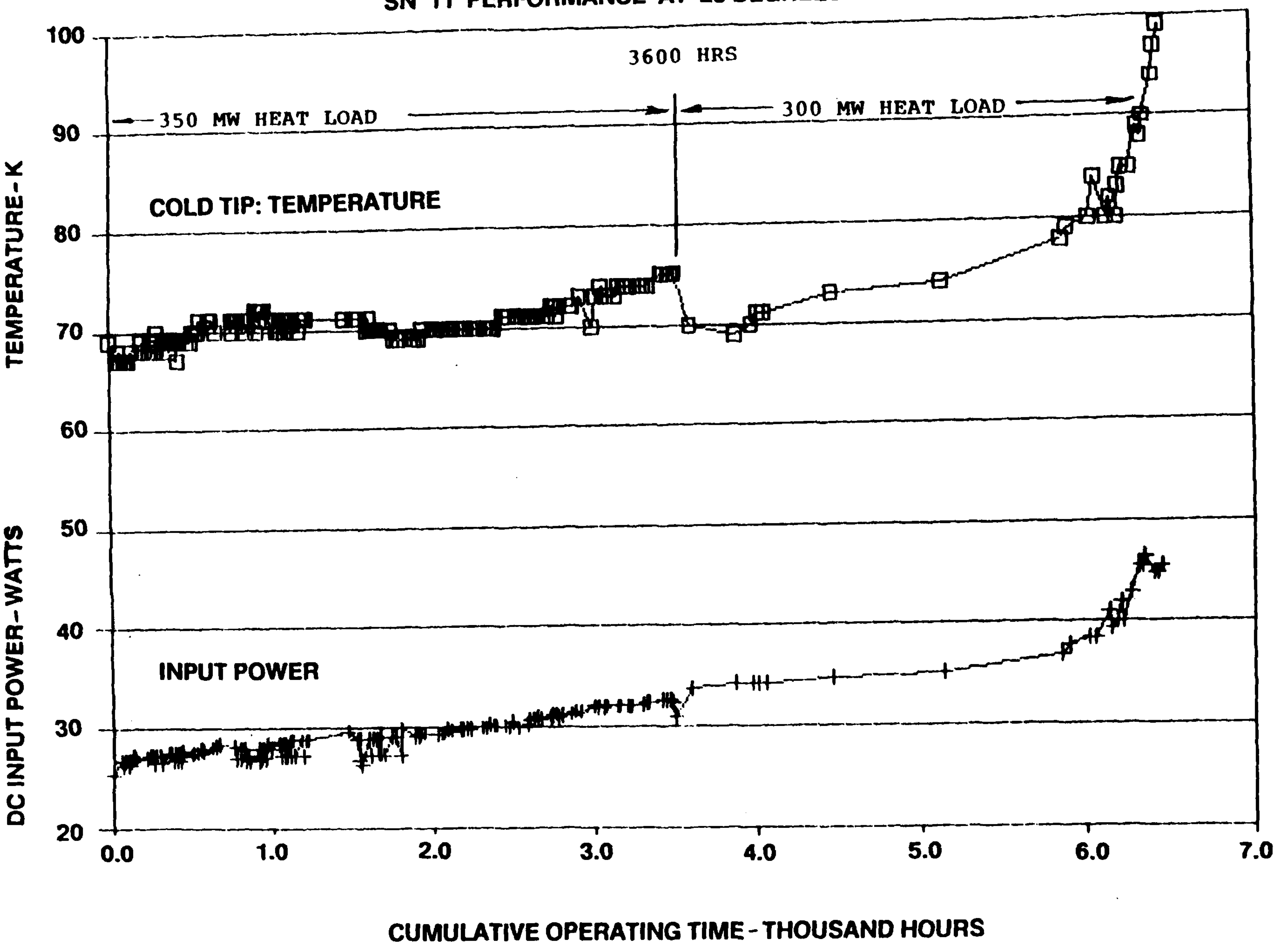
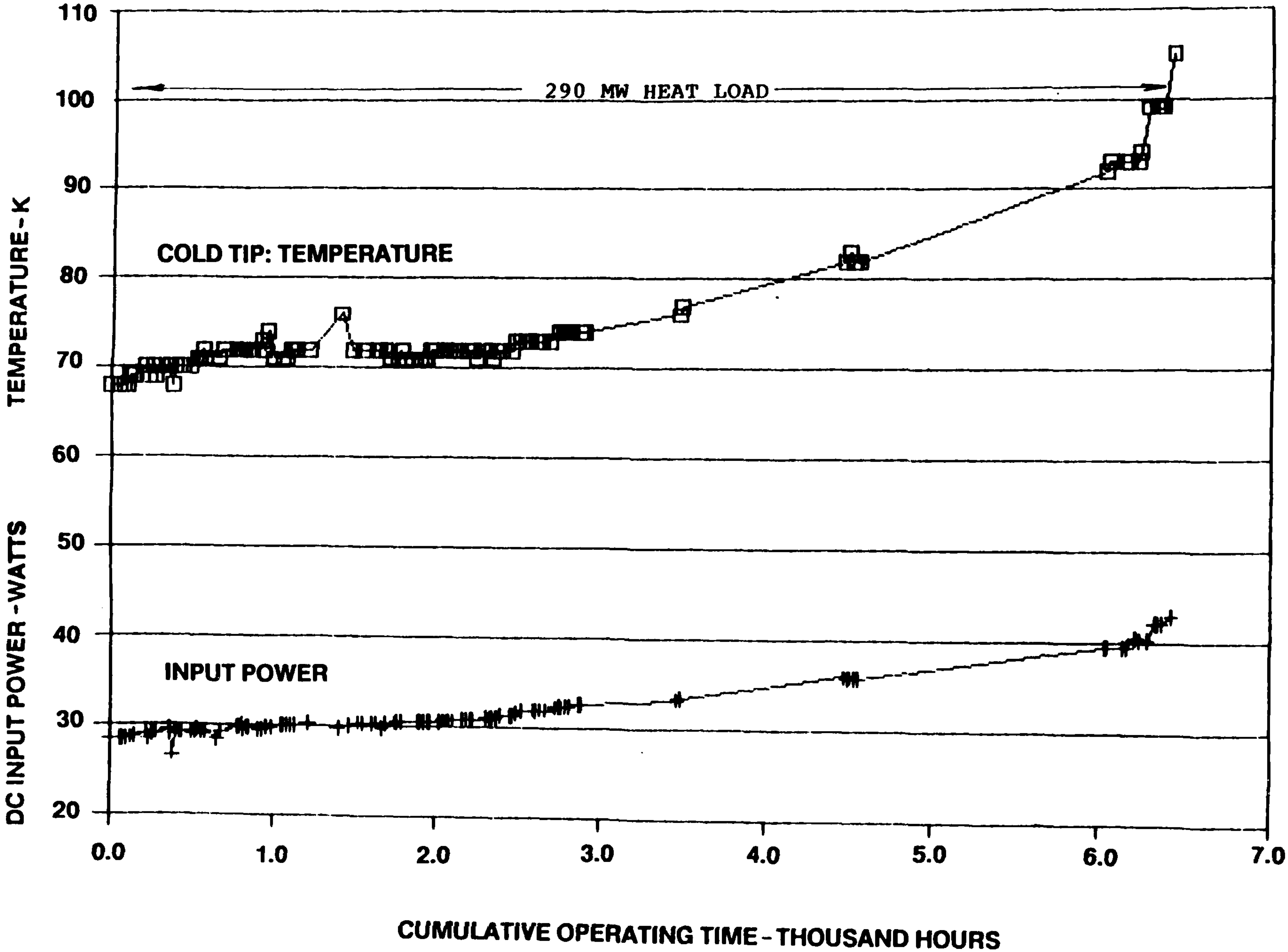


Figure 4.7.4.4-3.

MX 7045L COOLER LIFE TEST

SN 11 PERFORMANCE AT 52 DEGREES C



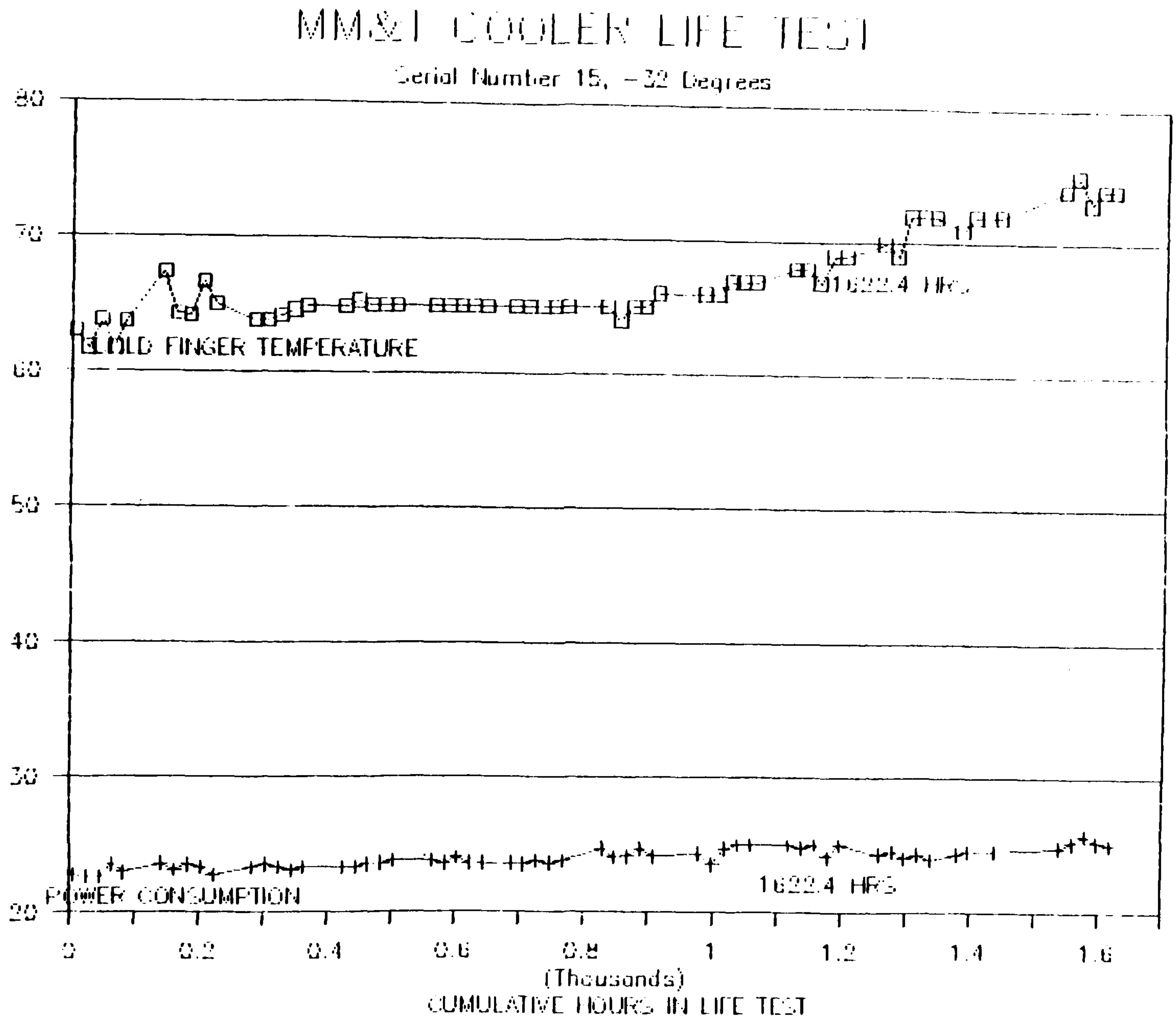


Figure 4.7.4.4-4

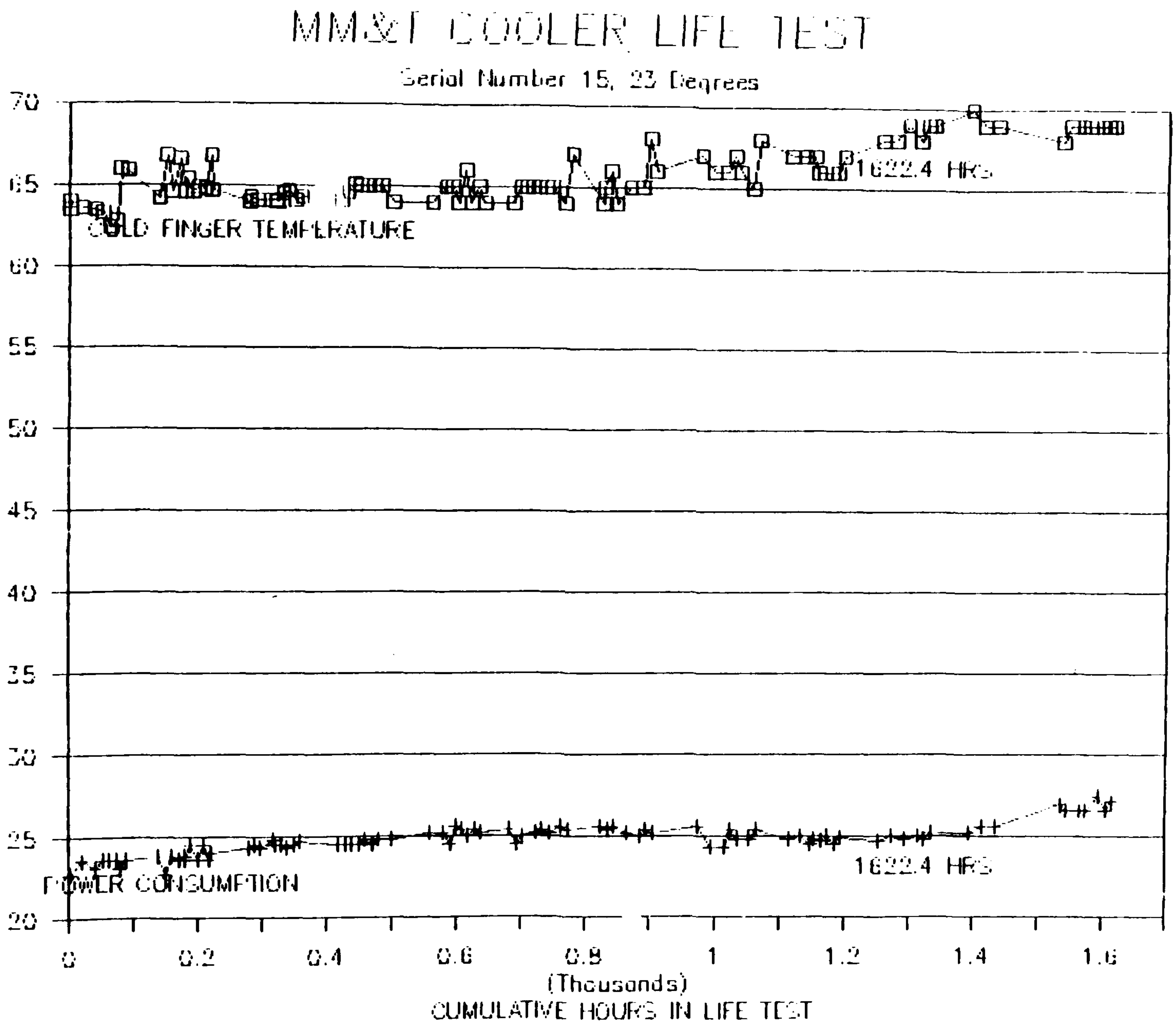


Figure 4.7.4.4-5

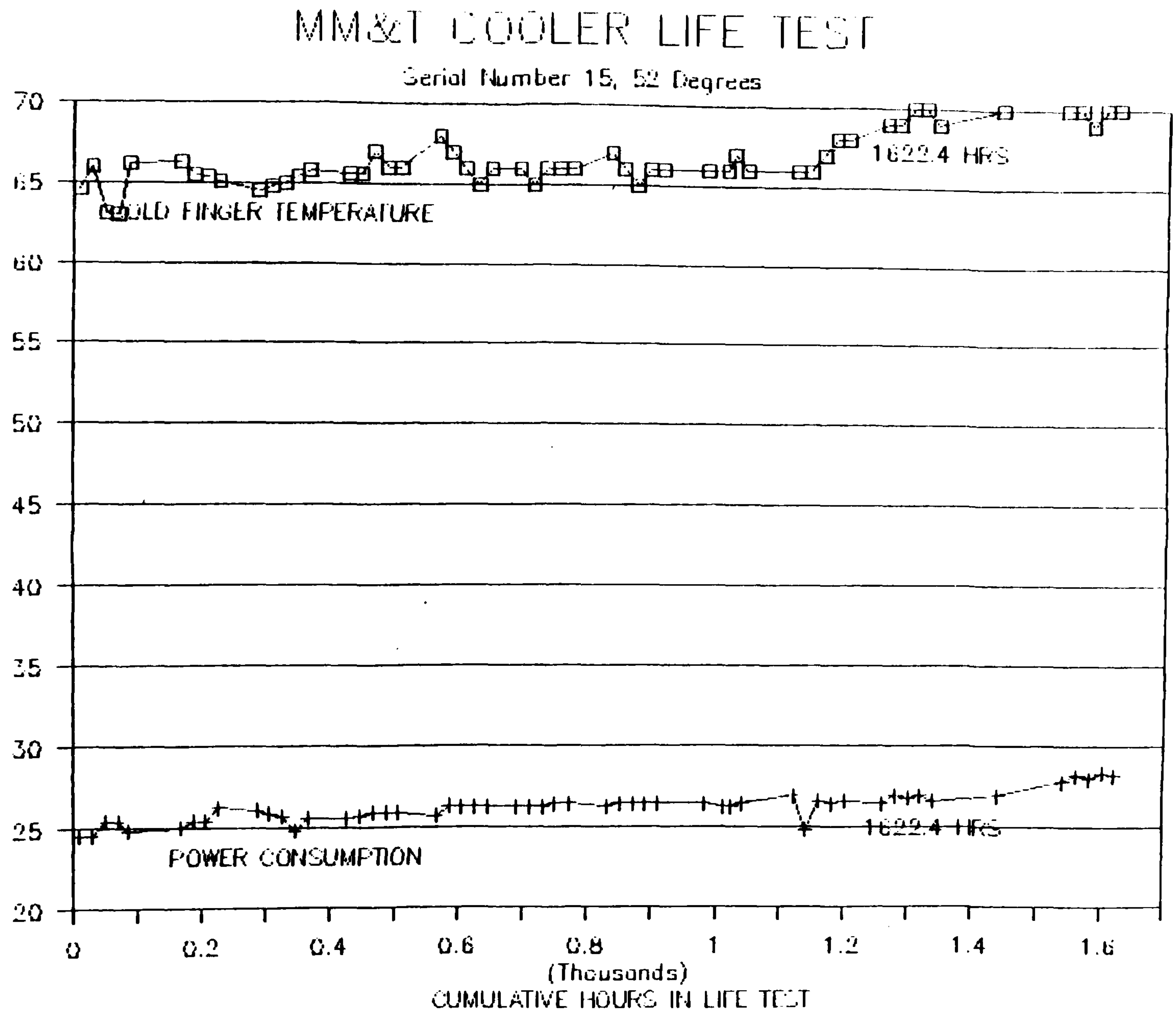


Figure 4.7.4.4-6

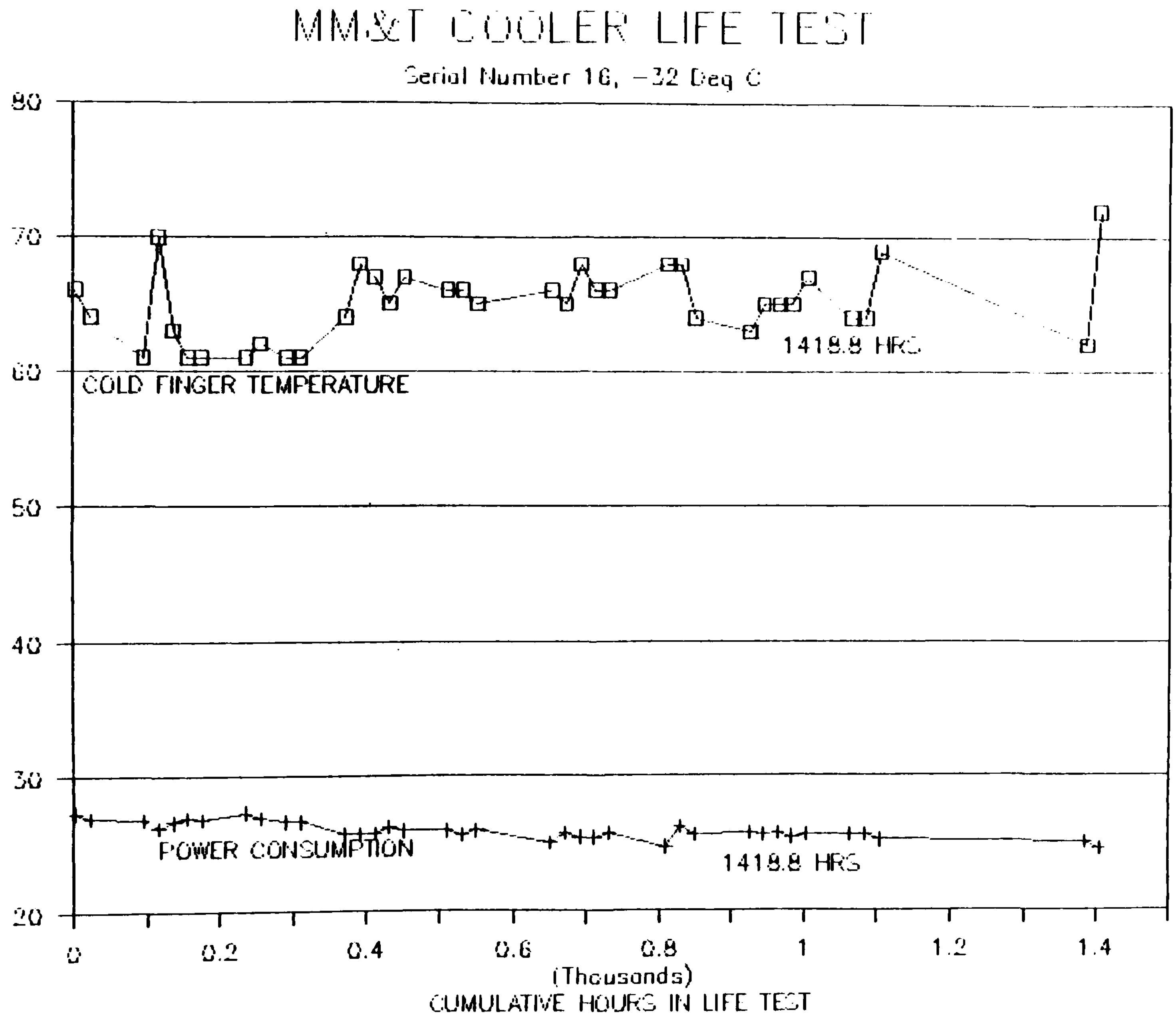


Figure 4.7.4.4-7

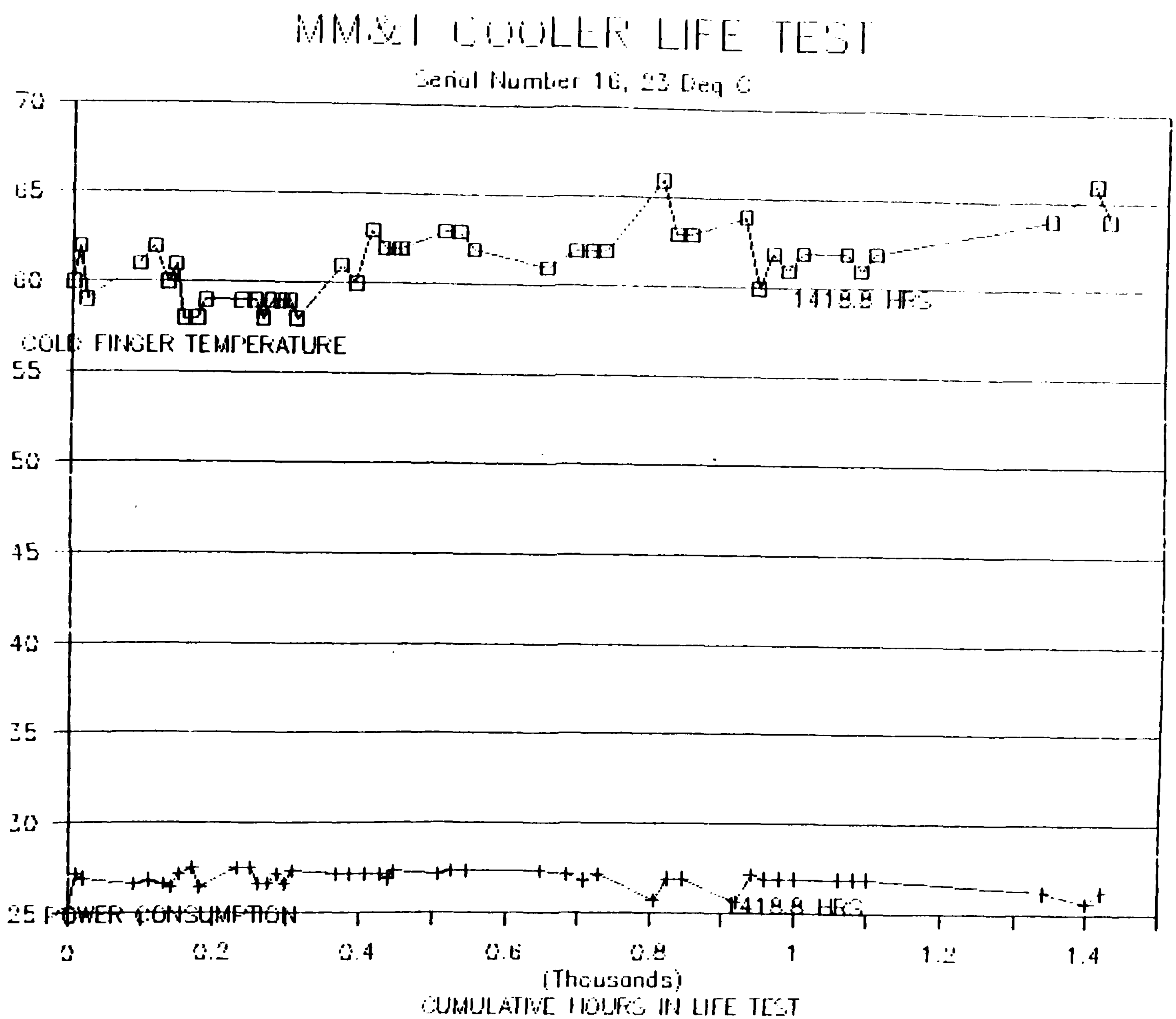


Figure 4.7.4.4-8

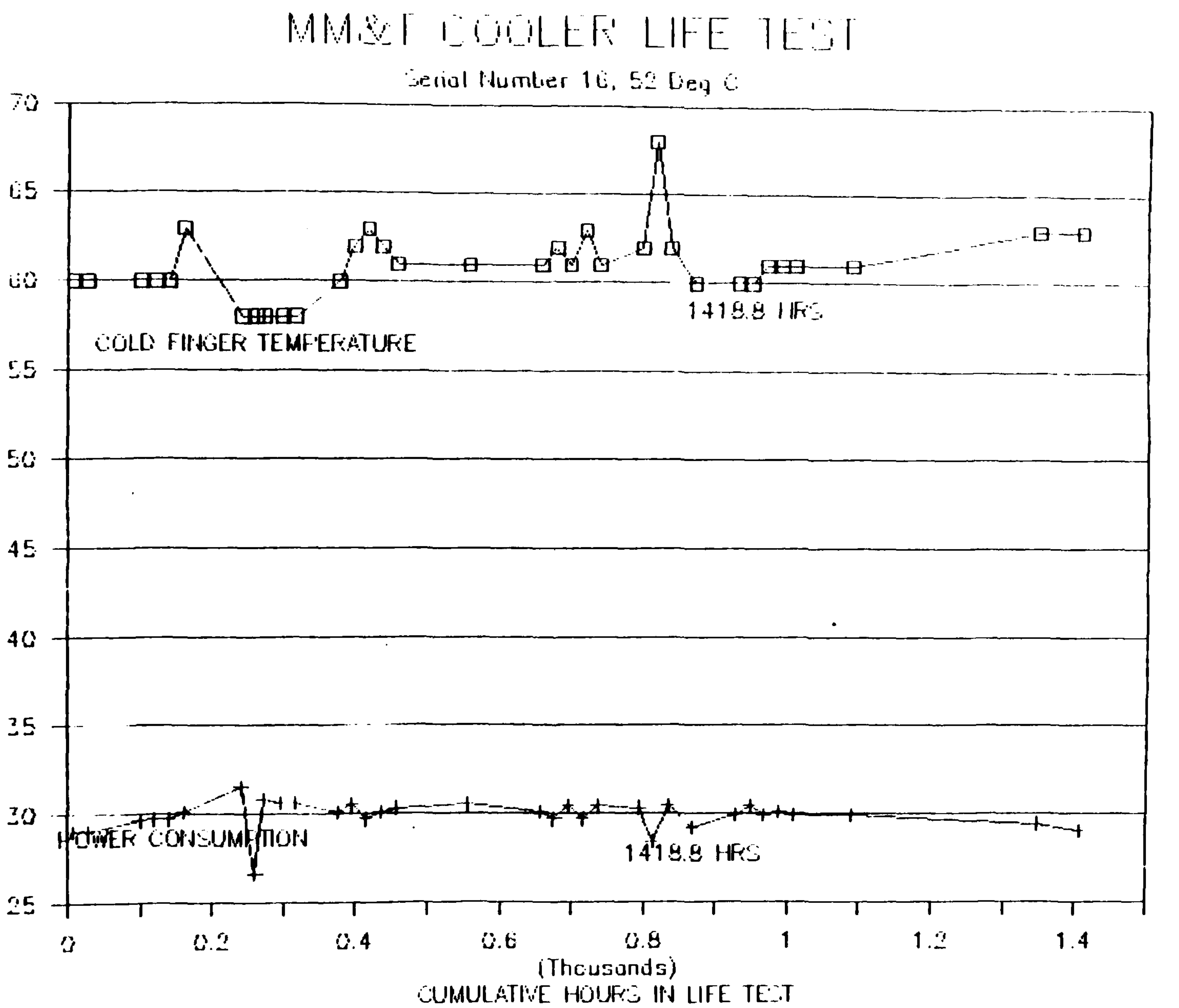


Figure 4.7.4.4-9

EXHIBIT 1

DEPARTMENT OF THE ARMY

U.S. ARMY WHITE SANDS MISSILE RANGE
WHITE SANDS MISSILE RANGE, NEW MEXICO 88002

REPLY TO
ATTENTION OF

STEWS-TE-AG

25 MAR 1987

SUBJECT: Final Report of Electromagnetic Interference Test of Special Study Magnavox Linear Drive Coolers, TECOM Project No. 6-ES-005-LDC-001

Commander
Center for Night Vision and Electro Optics
ATTN: DELNV-TS-FIRE (Mr. Henry Kling)
Fort Belvoir, VA 22060

1. Reference:

a. Letter, AMSTE-TE-C, TECOM, 8 Jan 87, subject: Test Execution Directive: Customer EMI Test, Special Study Magnavox Linear Drive Coolers, TECOM Project No. 6-ES-005-LDC-001.

b. EMI Test Plan, EOSR No. 1328A, 29 Jan 86, Linear Resonant Cooler HD 1045(v)/UA MM&T Program, Confirmatory Sample Phase Testing Part 1 and Part 3, Volume II.

c. MIL-STD-461A, Notice 4, Electromagnetic Interference Characteristics Requirements for Equipment.

2. Test Objective: To determine the electromagnetic interference (EMI) characteristics (emission and susceptibility) of the Magnavox Linear Resonant Split Stirling Cooler, and to determine if the requirements of MIL-STD-461A, Notice 4, were being adhered to.

3. Scope:

a. Two cooler units were provided for EMI testing (serial numbers 010 and 017). The EMI tests were performed in accordance with MIL-STD-461A, Notice 4, and MIL-STD-462B, Notice 3, at the Electromagnetic Radiation Effects (EMRE) Test Facility, White Sands Missile Range, NM during the period of 24 Feb through 2 Mar 87. The units were subjected to the test requirements as outlined in Table 1 (Encl 1).

b. A listing of the equipment used during the tests, as well as the test set-up and test personnel listing, is included in Encl 2.

Attachment 2

STEWS-TE-AG
SUBJECT: Final Report of Electromagnetic Interference Test of Special Study Magnavox Linear Drive Coolers, TECOM Project No. 6-ES-005-LDC-001

4. Summary of Results:

a. Method CE-01, Conducted Emissions, DC Power Leads, 30 Hz - 50 kHz.

(1) Serial Number 010: The emission levels measured during CE-01 testing are included in Encl 3, Figures 1 and 2. Figures 3 and 4 contain the ambient level readings taken without the cooler unit operating. All emissions were measured below the limit. This unit meets the requirements for CE-01 emissions.

(2) Serial Number 017: The emission levels measured during CE-01 testing are included in Encl 3, Figures 5 and 6. Figures 7 and 8 contain the ambient level readings taken without the cooler unit operating. All emissions were measured below the limit. This unit meets the requirements for CE-01 emissions.

b. Method CE-04, Conducted Emissions, Power Leads, 50 kHz - 50 MHz.

(1) Serial Number 010: The emission levels measured during CE-04 testing are included in Encl 3, Figures 9 through 12. With the 30 dB deviation applied, above limit broadband emissions still occurred on both the positive and negative power leads in the frequency range of 17 to 19.5 MHz. These signals were approximately 3 or 4 dB above the 30 dB deviation specified. This unit did not meet CE-04 requirements in the frequency range of 17 to 19.5 MHz, even with the 30 dB deviation.

(2) Serial Number 017: The emission levels measured during CE-04 testing are included in Encl 3, Figures 13 through 16. With the 30 dB deviation applied, above limit broadband emissions still occurred on both the positive and negative power leads in the frequency range of 15 to 20 MHz, with the maximum emission occurring at 10 dB above the 30 dB deviation point. This unit did not meet CE-04 requirements in the frequency range of 15 to 20 MHz, even with the 30 dB deviation.

(3) Ambient Conditions: The levels measured with both cooler units off (Ambient Conditions) are provided in Encl 3, Figures 17 through 20.

c. Method RE-01, Radiated Emissions, Magnetic Field, 30 Hz to 30 kHz.

(1) Serial Number 010: The emissions levels measured during RE-01 testing are included in Encl 3, Figures 21 through 24. Only those points at which the highest emissions were encountered are plotted on the graphs. With the 30 dB deviation applied, above limit emissions occurred at frequencies of 160 Hz (7 dB above specified limit) and 223 Hz (2 dB above specified limit). These signals were greatest when measured from the compressor end of the cooler.

(2) Serial Number 017: The emission levels measured during RE-01 testing are included in Encl 3, Figures 25 through 28. Only those points at which the highest emissions were encountered are plotted on the graphs. With the 30 dB deviation applied, above limit emissions occurred at frequencies of 160 Hz (7 dB above specified limit) and 223 Hz (2 dB above specified limit). These signals were greatest when measured from the compressor end of the cooler.

(3) Ambient Conditions: The levels measured with both cooler units off (Ambient Noise Level) are included in Encl 3, Figure 29.

d. Method RE-02/02.1, Radiated Emissions, Narrowband/Broadband, Electric Field, 14 kHz - 10 GHz.

(1) Serial Number 010: The emission levels measured during RE-02/02.1 are included in Encl 3, Figures 30 through 35. One set of measurements was taken with the heat sinks installed on the cooler unit and one set was taken with the heat sinks removed. There appeared to be less emissions with the heat sink off than with it on. With the 30 dB deviation applied, above narrowband limit emissions were recorded in the frequency range of 30 MHz to 40 MHz on both sets of measurements, with the maximum emission occurring about 5 dB above the 30 dB deviation point. This unit did not meet RE-02/02.1 requirements, even with a 30 dB deviation.

(2) Serial Number 017: The emission levels measured during RE-02/02.1 testing are included in Encl 3, Figures 36 through 38. Measurements were taken with the heat sinks on the cooler unit since this was the worst case configuration. With the 30 dB deviation applied, above narrowband limit emissions were recorded in the frequency range of 25 MHz to 42 MHz, with the maximum emission occurring about 10 dB above the 30 dB deviation point. This unit did not meet RE-02/02.1 requirements, even with a 30 dB deviation.

(3) Ambient Conditions: Encl 3, Figures 39 and 41 contain the measurements taken without the cooler units operating.

e. RS-03, Radiated Susceptibility, 14 kHz - 10 GHz.

(1) Serial Number 010: The cooler unit was subjected to radiated fields as shown in Encl 3, Figure 42. The field intensity, modulation, and polarization are also listed in Figure 42. The cooler unit was visually observed for any performance degradation (via the "Cold Finger"). In addition, an ammeter was connected to the cooler to monitor input current deviations which would indicate possible cooler malfunctions. There was no apparent degradation in performance of the cooler unit when subjected to these fields, except for slight current drop (about .25 amps) and shortening of the linear motor stroke (probably to compensate for the slight current drop) at 10.46 MHz on amplitude modulation, horizontal polarization.

STEWS-TE-AG
SUBJECT: Final Report of Electromagnetic Interference Test of Special Study Magnavox Linear Drive Coolers, TECOM Project No. 6-ES-005-LDC-001

(2) Serial Number 017: The cooler unit was subjected to the same radiated fields shown in Encl 3, Figure 42. There was no apparent degradation of performance of the cooler unit when subjected to these fields, except for a slight current drop (about .25 amps) and shortening of the linear motor stroke at 10.46 MHz and 13.964 MHz on amplitude modulation, horizontal polarization.

5. The point of contact at Army Materiel Test and Evaluation (ARMTE) Directorate is Mr.David J. Ribail, AUTOVON 258-6107.

6. WSMR - Providing Soldiers the Decisive Edge.

FOR THE COMMANDER:

William G. Frye

3 Encls

WILLIAM G. FRYE
Deputy Director
Army Materiel Test and Evaluation

Table 3.1 Tests To Be Performed

MIL-STD-461 REQUIREMENT	DESCRIPTION	DEVIATION PER B2-28A050122A
RE 01	Radiated emission/magnetic field, 30 Hz to 30 kHz	30 dB
RE 02 BB	Radiated emissions/electric field, 14 kHz to 1 GHz	30 dB
RE 02.1 NB	Radiated emissions/electric field, 14 kHz to 10 GHz	30 dB
* RS 03	Radiated susceptibility/electric field, 14 kHz to 10 GHz	Notes 1 & 2
CE 01	Conducted emissions/dc power leads, 30 Hz to 50 kHz	30 dB
CE 04	Conducted emissions/power leads, 50 kHz to 50 MHz	30 dB

*Notes:

1) The field strengths specified in MIL-STD-461 shall be modified as follows:

0.014 MHz to 2 MHz	10 volts per meter
2 MHz to 76 MHz	50 volts per meter
76 MHz to 10,000 MHz	10 volts per meter

2) The following modulation shall be used:

10 kHz to 30 MHz	AM, 50%, 1000 Hz tone
76 MHz to 400 MHz	AM, 50%, 1000 Hz tone
30 MHz to 76 MHz	FM, ±8 kHz Dev., 1000 Hz tone
400 MHz to 10 GHz	Pulse 1 microsec. 800 PPS

ENCLOSURE (1)

1. Equipment used: See Table A.1

2. Personnel:

David J. Ribail	EMRE test engineer
Richard Worley	EMRE test technician
Keith Bond	EMRE test technician
Gary Babcock	EMRE test technician

3. Test Set-up:

The test set-ups for conducted emissions, radiated emissions, and radiated susceptability tests are shown in Figures A.1 - A.4.

ENCLOSURE (2)

Table A-1. Test Equipment List

Equipment	Manufacturer	Model	Serial Number
Antennas:			
Magnetic Loop	Ailtech		
41 Inch Active Rod	EMCO	3301	2111
High Power Biconical	EMCO	3109	2231
Conical Log-Spiral	EMCO	3101	3073
Conical Log-Spiral	EMCO	3102	2640
Double Ridge Guide	EMCO	3106	2296
Dish Feedhorn Assy	AYDIN		
Dish Feedhorn Assy	FAM		
Amplifiers:			
Small Signal Amp	HP	8447D	2443A01223
Small Signal Amp	HP	8349B-HO1	2644A01223
R.F. Amplifier (20W)	IFI	5300	0983-2505
R.F. Amplifier (1KW)	IFI	406A	1172782
R.F. Amplifier (5W)	RF PWR LABS	M505	52168
R.F. Amplifier (500W)	M.P.D.	30-140A	----
R.F. Amplifier	AYDEN	1318	NONE
R.F. Amplifier	F.A.M.	418	617
R.F. Amplifier	LOGIMETRICS	A600/U	6110-200
Signal Generators:			
RF SYN. SIG. GEN.	HP	8660C	2142A04156
RF PLUG IN	HP	86601A	2223A02349
RF PLUG IN	HP	86603A	2221A02995
MODULATION PLUG IN	HP	86632B	2238A02036
PULSE MOD. PLUG IN	HP	86631B	1314A02470
RF SYN. SIG. GEN	HP	8672A	2115A01830
RF TWT SIG. GEN	ALFRED	650	1540
RF TWT SIG. GEN	ALFRED	650	291
RF PLUG IN	ALFRED	651	753
RF PLUG IN	ALFRED	652	764
RF PLUG IN	ALFRED	653	550
RF PLUG IN	ALFRED	655	551
Pulse Generator	DATAPULSE	101	79117
Data Processing:			
Computer	HP	9836A	2440A12074
Printer	HP	2225A	2627S30450
Plotter	HP	7550A	2631A35987
EMI Software	HP	85864C	
Miscellaneous:			
AMMETER	SIMPSON		
Current Probe	EATON	91197-1L	494
Current Probe	SINGER	94111-1	0153-04049
EMI Receiver System	HP		
Spectrum Analyzer	HP	8566B	2152A0359
S.A. Display Unit	HP	8566B	2140A01298
RF Preselector	HP	85685A	2620A00258
Quasi-Peak Adapter	HP	85650A	2521A 00761

TABLE A.1. CONTINUED

!: Meter	AILTECH	NM-7A	
.: S.N.	SOLAR	6338-57-TS	NONE
.I.S.N.	SOLAR	6338-57-TS	NONE
.I S.N.	SOLAR	6338-5-TS	NONE
. S.N.	SOLAR	6338-5-TS	NONE
Digital Multimeter	FLUKE	8060A	3735169
Frequency Counter	SYSTRON DON	6054B	11027-8
. Measurement:			
- ELD	IFI	EFS-1	87
Power Meter	HP	431C	747-10253
Power Sensor	HP	8478B	NONE
/ Field Meter	AERITALIA	TE307	4005
-FIELD PROBE 100V/M	AERITALIA	19RV1001-2	5053
-FIELD PROBE 100V/M	AERITALIA	14RV1001-1	3024

CE-01,04
Test Set-Up

1. 5 cm STANDOFFS
2. LOW IMPEDANCE [illegible] BOND TO GROUND PLANE
3. CURRENT PROBE
4. TEST SAMPLE CHASSIS GROUND
5. HIGH SIDE
6. RETURN (neutral line)
7. DC BOND IMPEDANCE BETWEEN THE GROUND PLANE AND ENCLOSURE SHALL NOT EXCEED 2.5 MILLIOHMS.
8. LINE IMPEDANCE STABILIZATION NETWORKS SHALL BE TERMINATED IN 50 OHM RESISTIVE AT TYPE N CONNECTOR

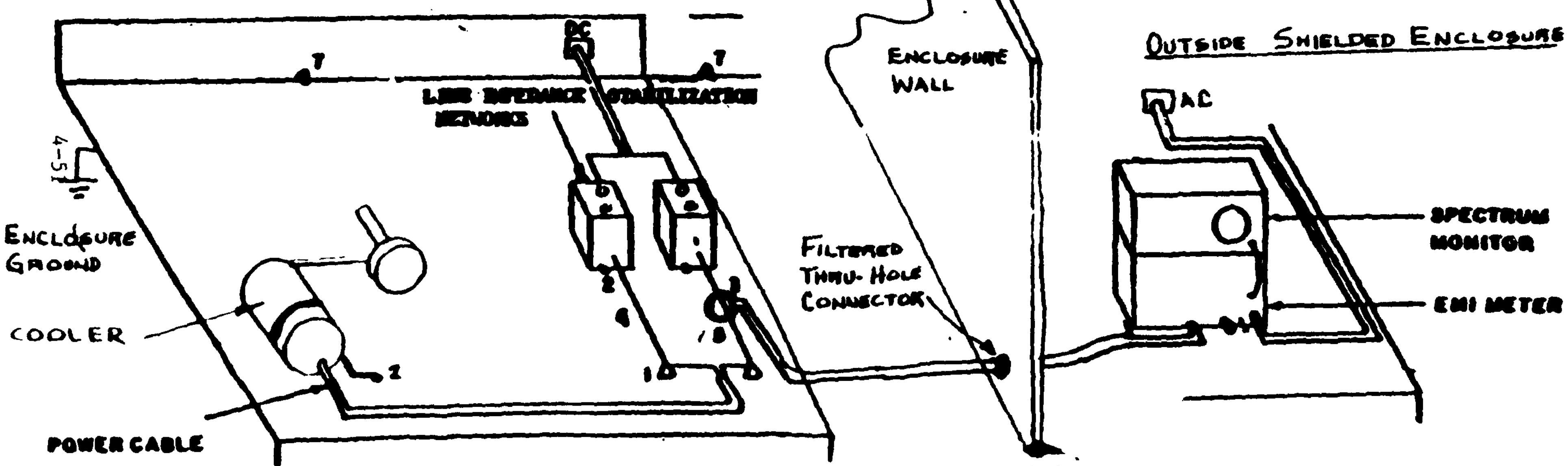


figure TYPICAL TEST SETUP FOR CONDUCTED EMISSION MEASUREMENTS ON POWER LEADS

FIGURE A.1

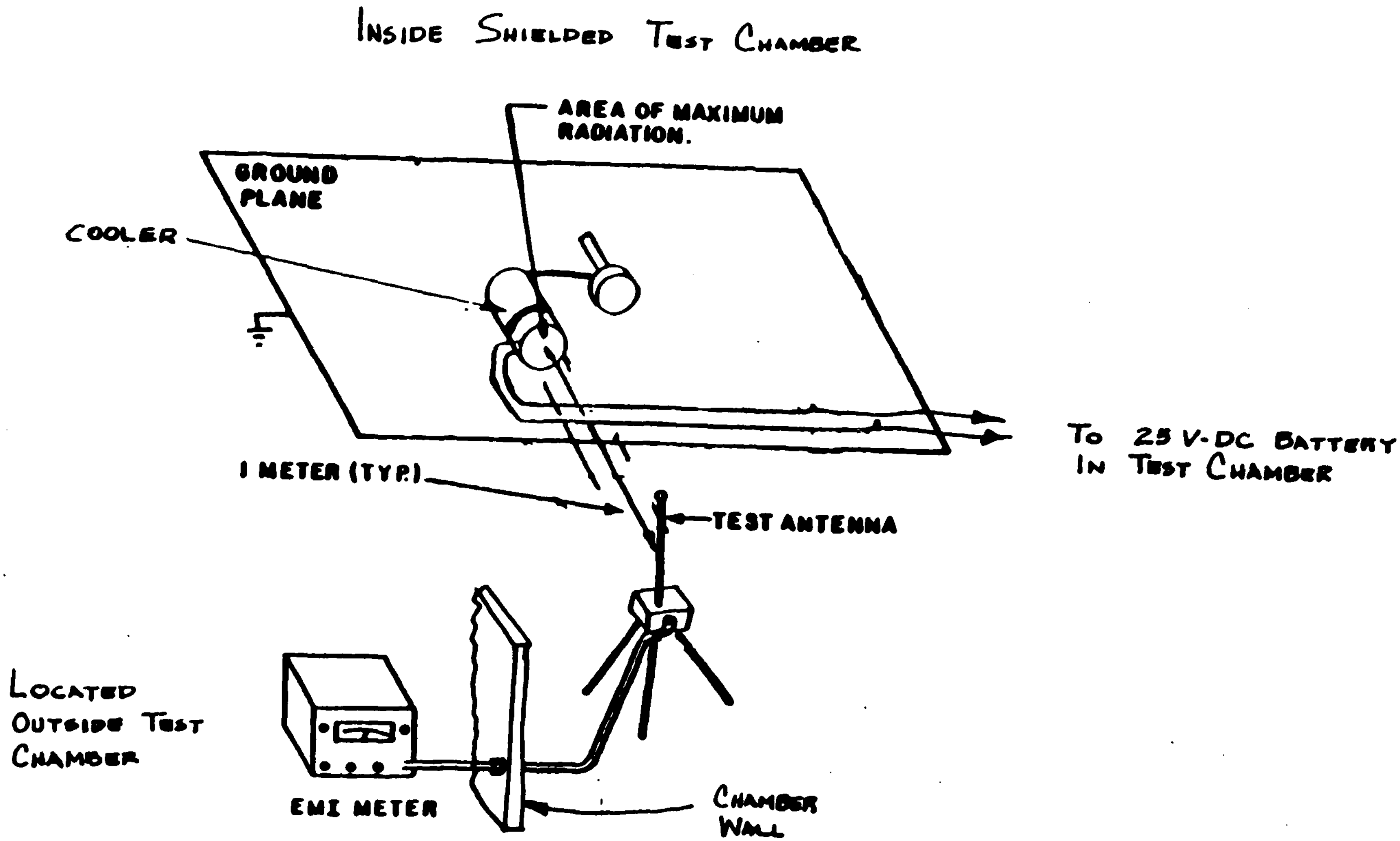


Figure Typical Test Setup for Radiated Measurements (RE-02/02.1)

FIGURE A.2

Linear Cooler-
Test Configurations
RE-01

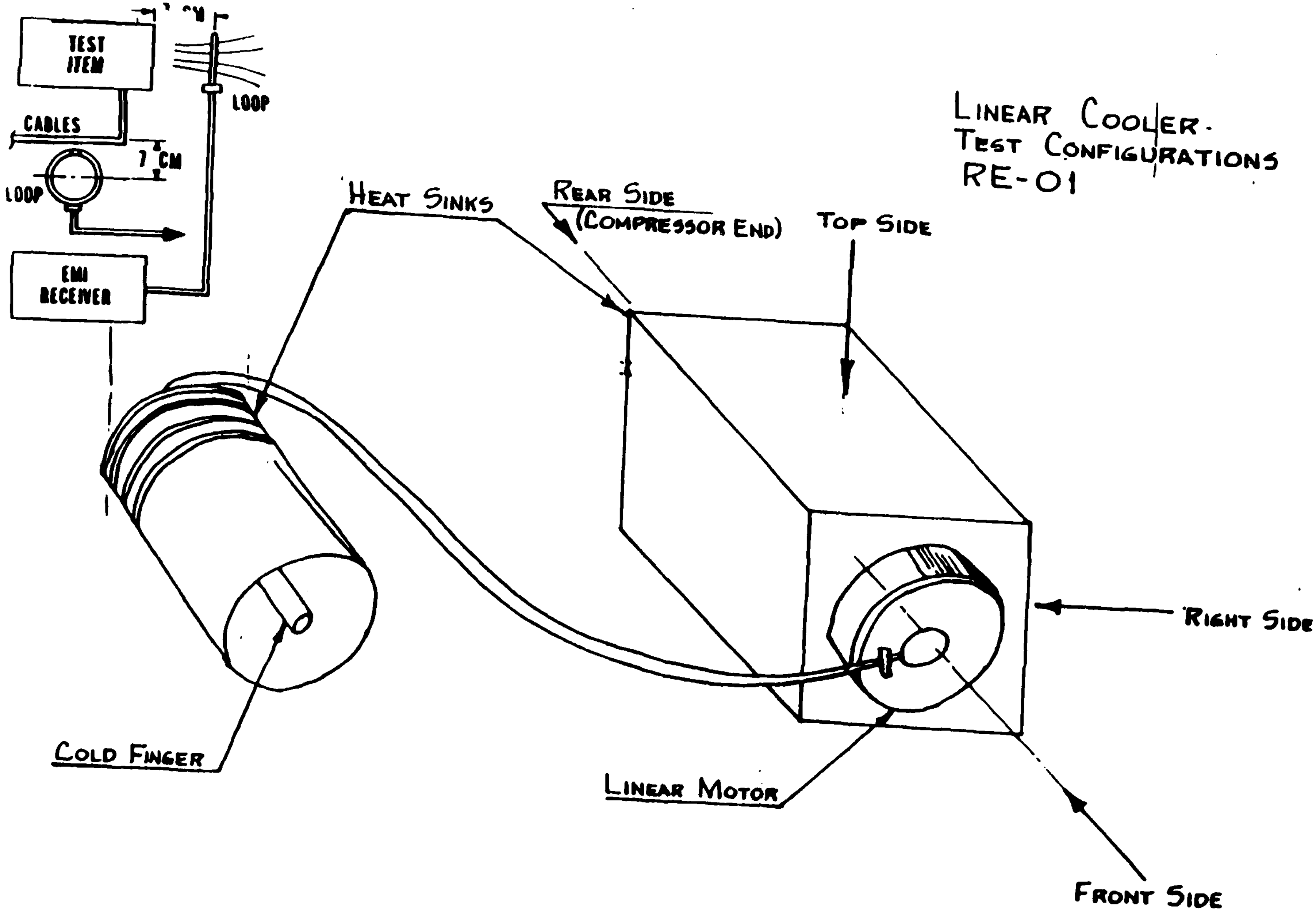
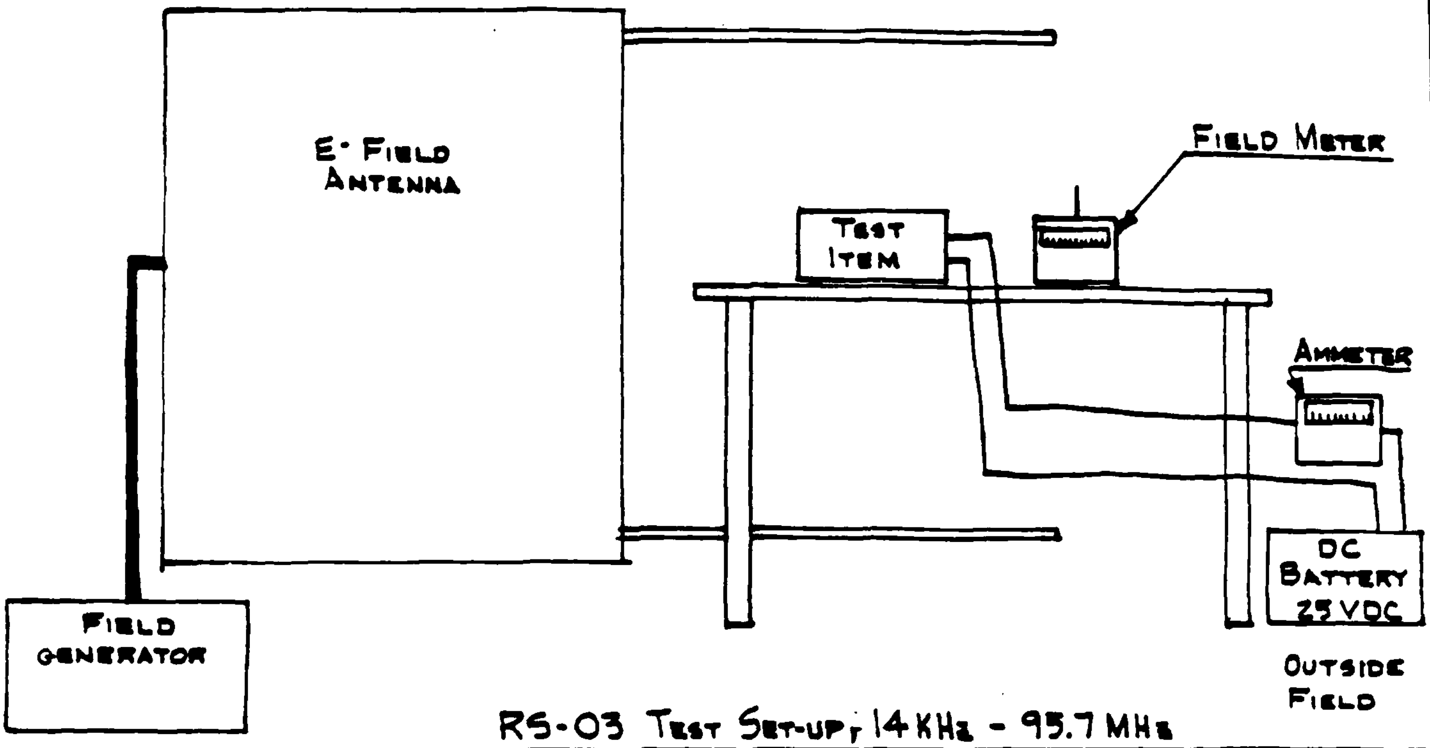
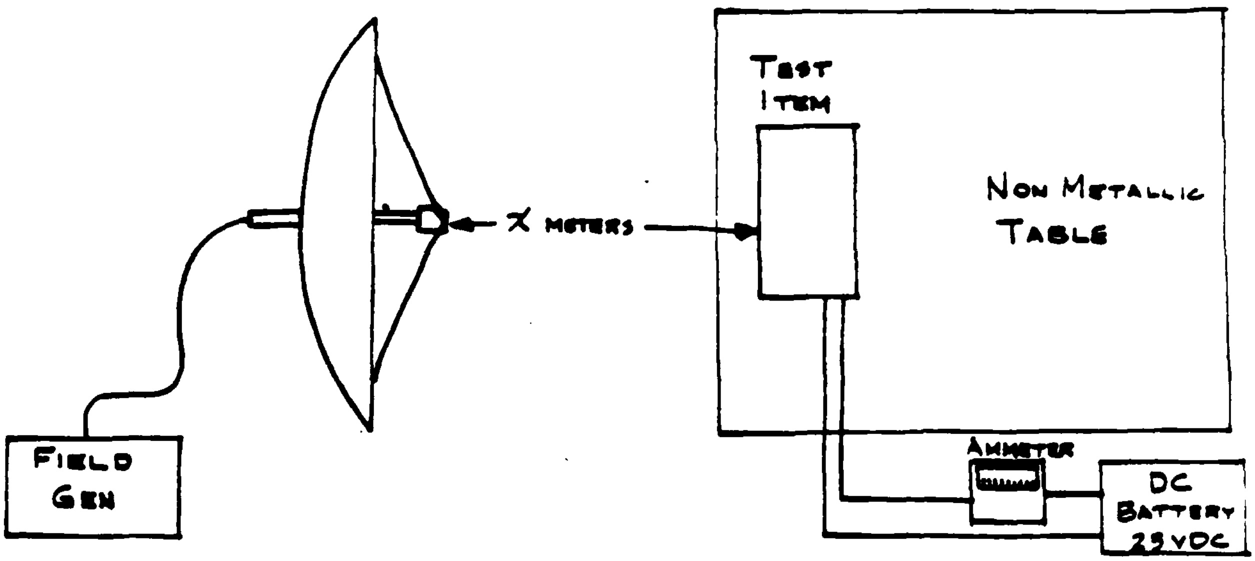


Figure A.3



RS-03 TEST SET-UP, 14 KHz - 95.7 MHz

A. 241.5 MHz - 355 MHz, x = 1 METER
. 508 MHz - 942 MHz, x = 100 FEET (DISTANCE AT WHICH FIELD WAS 10 V/M)
C. 1.25 GHz - 10 GHz, x = 50 FEET (" " " " " ")



RS-03 TEST SET-UP, 241.5 MHz - 10 GHz

FIGURE A.4

5.0 MANUFACTURING METHODS

This section presents a detailed discussion of the manufacturing methods that were developed for the purpose of mass producing the cooler while assuring consistent quality and reliability. The cooler manufacturing process is broken up into eight procedures (see Figure 5.0-1), seven of which produce the major subassemblies and the eighth procedure describes final assembly.

The major subassemblies are:

1. Displacer subassembly
2. Housing subassembly
3. Front cap inner iron subassembly
4. Housing, magnet and cap assembly
5. Coil winding subassembly
6. Coil and vibration absorber subassembly
7. Driver electronics subassembly

The following paragraphs describe the manufacturing procedures for the subassemblies listed above. The subassembly manufacturing is followed by the final assembly procedure.

5.1 DISPLACER ASSEMBLY

The following steps describe the procedure required to assemble the displacer assembly.

Components: rear spool, regenerator body, front cap and wire mesh, clearance seal sleeve

5.1.1 BOND AND CURE

a) Clean the components thoroughly and vacuum bake the parts.

b) Apply epoxy to the O.D. at one end of the regenerator body and attach the rear spool.

c) Align the subassembly using a V-block and a clamp (see Figure 5.1.1-1).

d) Place the unit in the oven and cure.

5.1.2 DISC STACKING

a) Place the spool and body assembly in the holding fixture (Figure 5.1.2-1).

b) Place the regenerator discs in five clean vials, each containing 290 milligrams of discs.

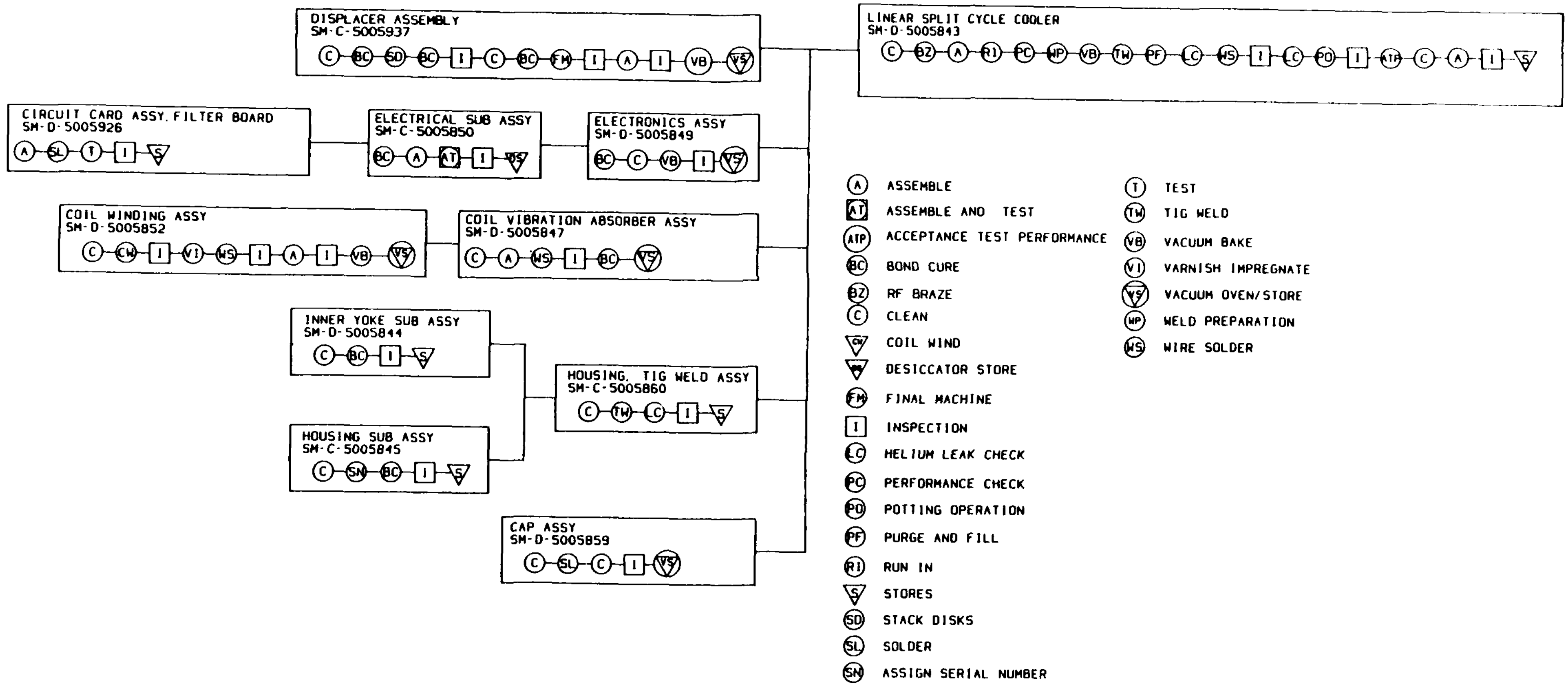


Figure 5.0-1. Manufacturing Flow Diagram

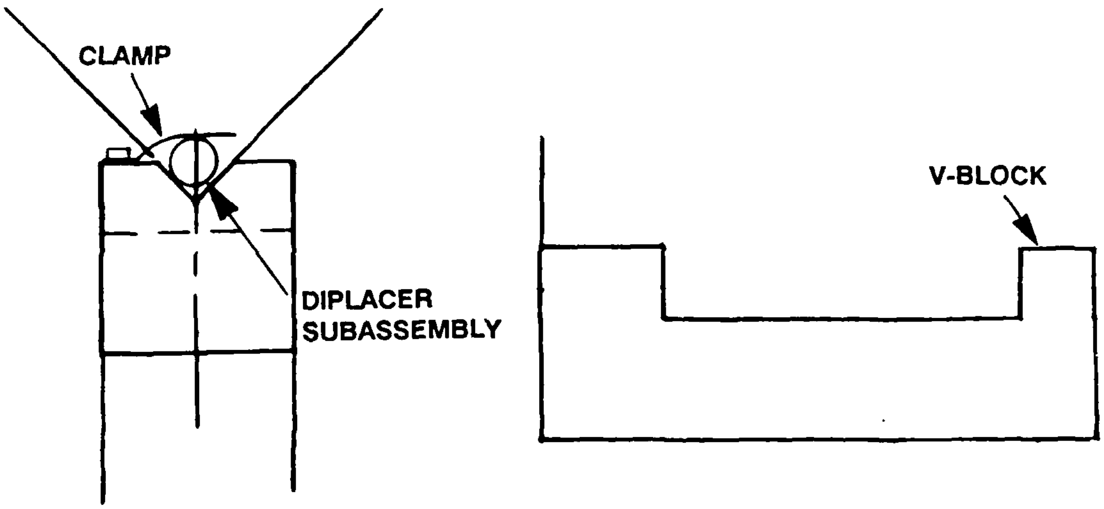


Figure 5.1.1-1. Displacer Bonding Fixture

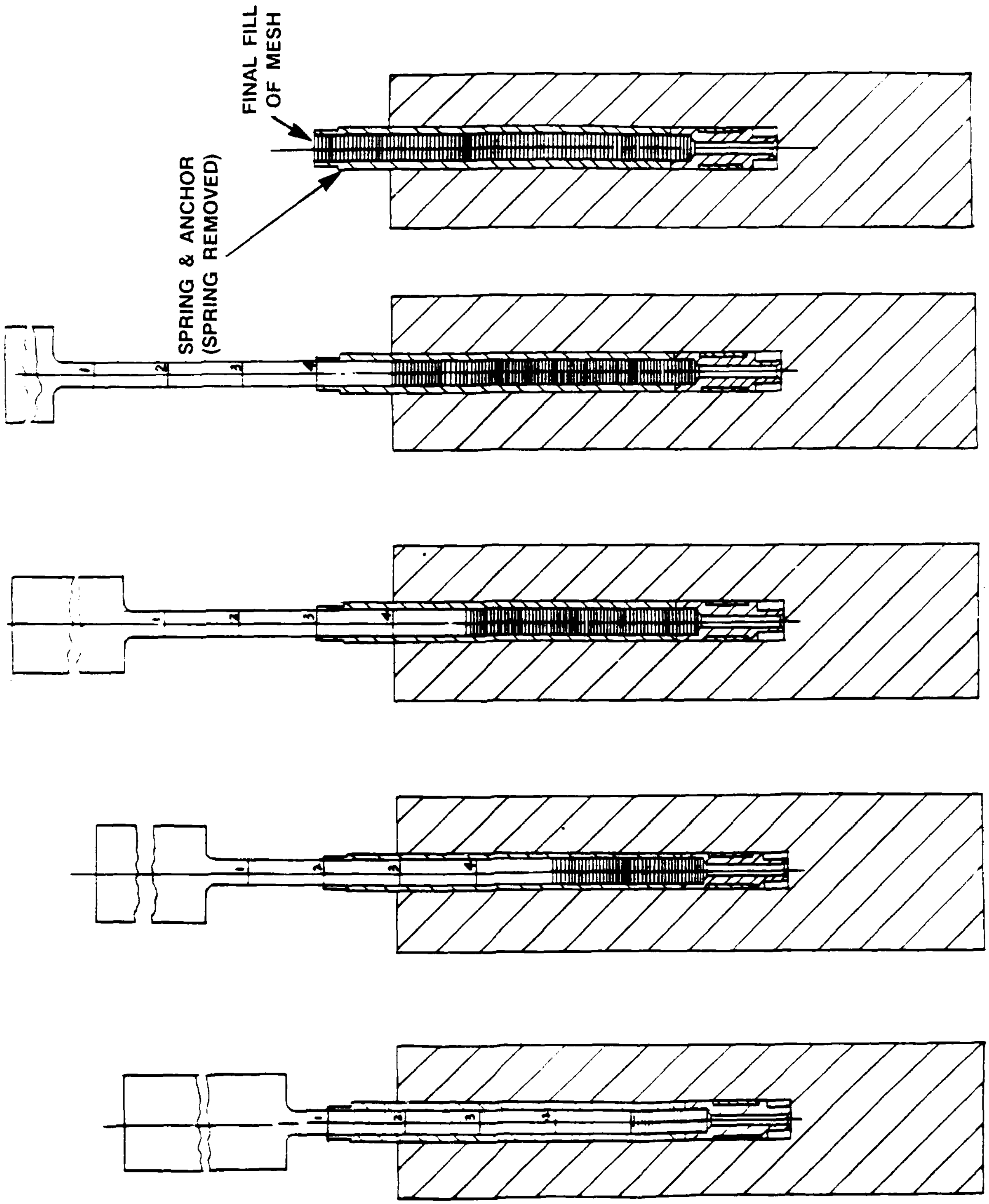


Figure 5.1.2-1. Displacer Mesh Stacking Fixture

c) After loading the first vial of discs in the body, use the gauge rod to pack it tightly so that the mark "1" on the rod coincides with the end of the regenerator body.

d) Continue the process until all the discs in the five vials are loaded and uniformly packed.

5.1.3 BOND AND CURE (FINAL MACHINE AND ASSEMBLY)

a) Apply epoxy at the unbonded end of the body.

b) Attach the front cap to the body.

c) Clamp the assembly into the alignment fixture and cure.

d) Remove the assembly from the fixture at room temperature.

e) Apply epoxy on the rear spool and heat-shrink fit the clearance seal sleeve.

f) Epoxy cure the assembly.

g) Mount the assembly on a clean lathe and final machine the clearance seal to the required diameter (Figure 5.1.3-1.).

h) Assemble the spring and the spring anchor as shown to obtain the overall design length (Figure 5.1.3-2).

5.2 <u>HOUSING SUBASSEMBLY</u>

The following steps describe the procedure required to assemble the housing subassembly.

<u>Components</u>: inner iron, front cap, magnet assembly, compressor housing

5.2.1 <u>Housing and Magnet Subassembly</u>

a) Clean the compressor housing and magnet subassembly.

b) Assemble the magnet assembly onto the bonding fixture and tighten the nut called out in Figure 5.2.1-1.

c) Apply a thin coat of epoxy onto the internal surface of the compressor housing.

d) Slide the magnet assembly into the housing so that the tool is seated properly against the housing (see figure 5.2.1-2). Install an end cap and tighten the hex nut.

e) Cure the assembly and remove the bonding fixture from the assembly.

f) Fill in X-Y area depicted in Figure 5.2.1-2 with epoxy and recure the assembly.

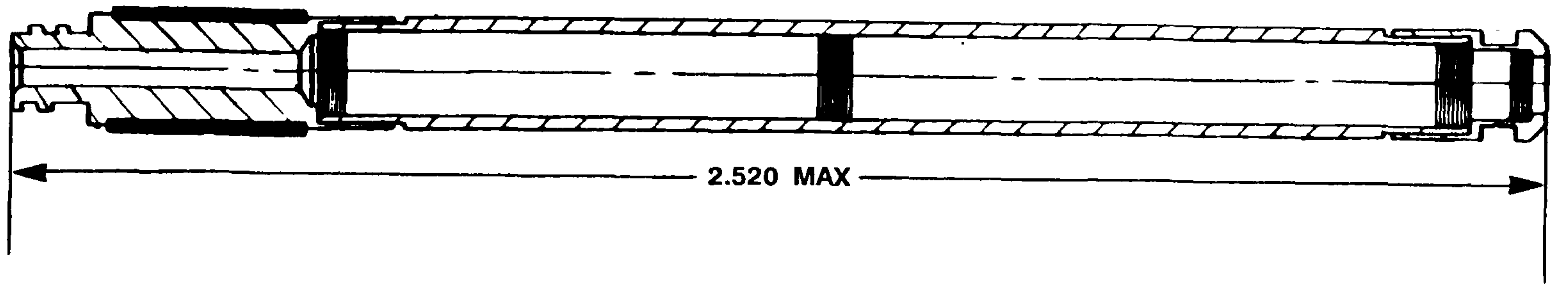


Figure 5.1.3-1. Displacer Subassembly

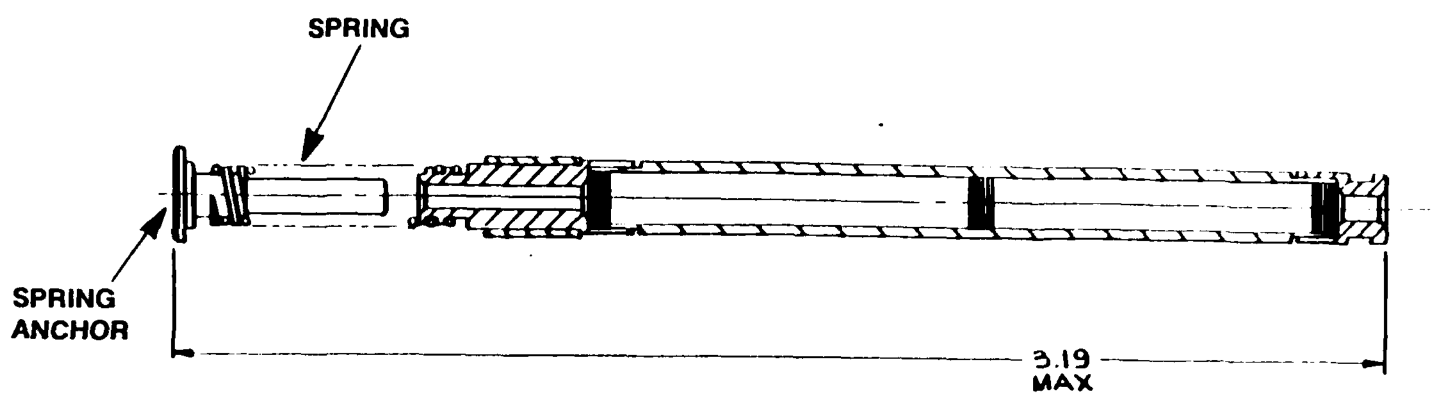


Figure 5.1.3-2. Displacer and Restoring Spring Subassembly

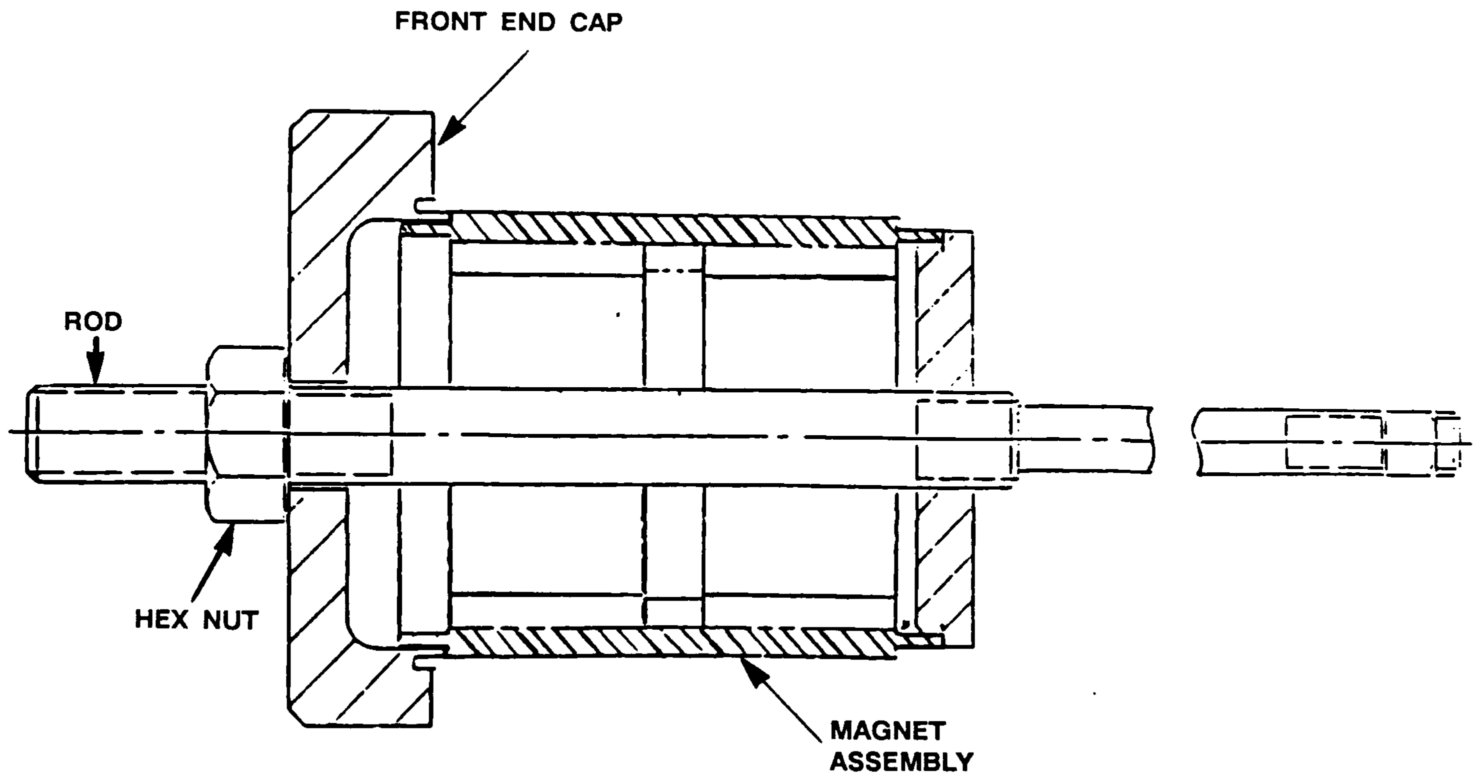


Figure 5.2.1-1. Magnet Holding Fixture

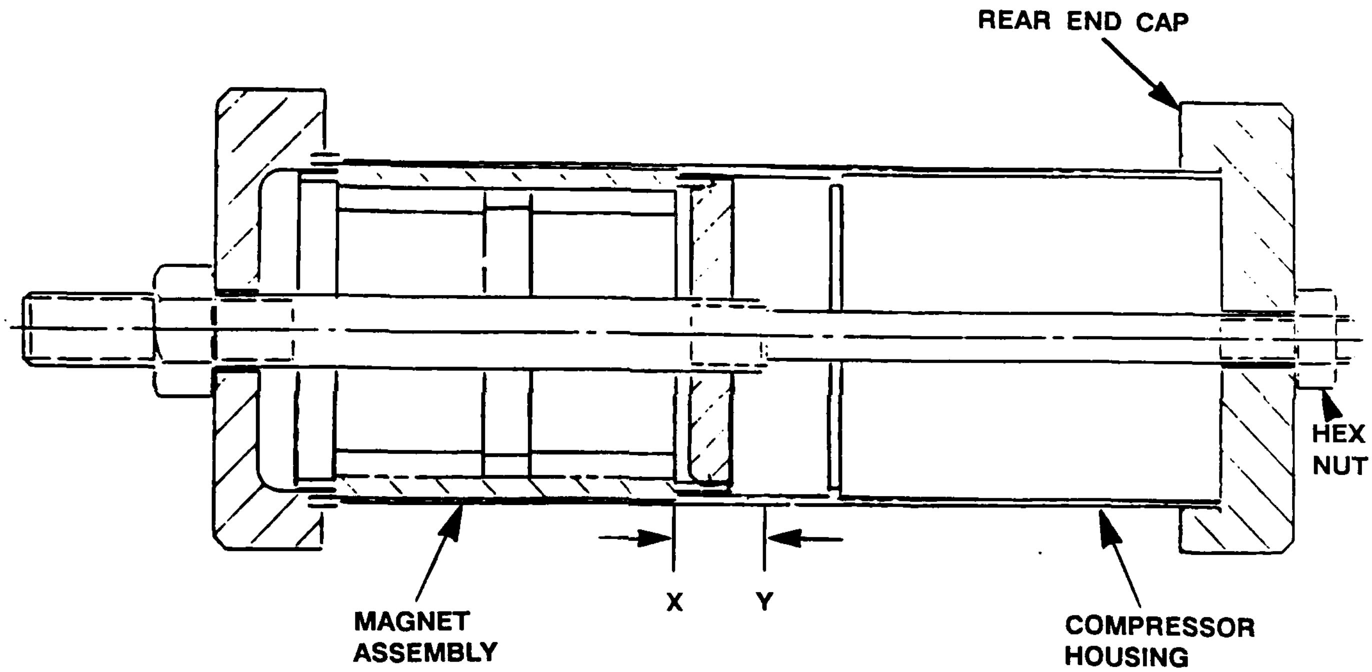


Figure 5.2.1-2. Housing and Magnet Bonding Fixture

5.3 FRONT CAP - SUBASSEMBLY

The following steps describe the procedure required to assemble the front cap subassembly.

Components: inner iron, front cap and epoxy

a) Clean the inner iron and front cap.

b) Thread the inner iron onto the cap until it bottoms against the shoulder of the cap and disassemble the parts.

c) Apply the epoxy onto the cap thread and thread the inner iron to achieve the required bore depth.

d) Slide the subassembly onto the bonding fixture as shown in Figure 5.3-1.

e) Cure the epoxy bond and remove the assembly from the fixture. Make sure that there is no excess epoxy inside the bore at the joint. The completed assembly is as shown in Figure 5.3-2.

5.4 HOUSING - MAGNET AND CAP SUBASSEMBLY

The following steps describe the procedure required to assemble the housing-magnet subassembly and cap subassembly.

Components: housing magnet subassembly and front cap subassembly

a) Clean the housing magnet and front cap subassembly.

b) Insert the alignment tool into the rear of the housing.

c) After the tool is fully inserted, the front cap assembly shall be inserted into the bore of the tool. See Figure 5.4-1.

d) The lip of the cap should be in line-to-line contact with the weld end of the housing when the cap is pushed flush.

e) Install the heat sinks on the TIG lathe. Connect the housing heat sink gas line to a supply of inert gas (argon).

f) Install the cooler housing subassembly in the heat sink by carefully sliding it into place. Next move up the tail stock and engage the cap heat sink. The final position is as shown in Figure 5.4-2. Install a plug in the open union tube.

g) Position the torch over the weld area so that the tip of the electrode is directly above the joint to be welded.

h) With the argon gas flowing towards the weld area the welding is accomplished with the assembly rotating at 200 - 300 rpm and the weld current set at 25 to 30 amps.

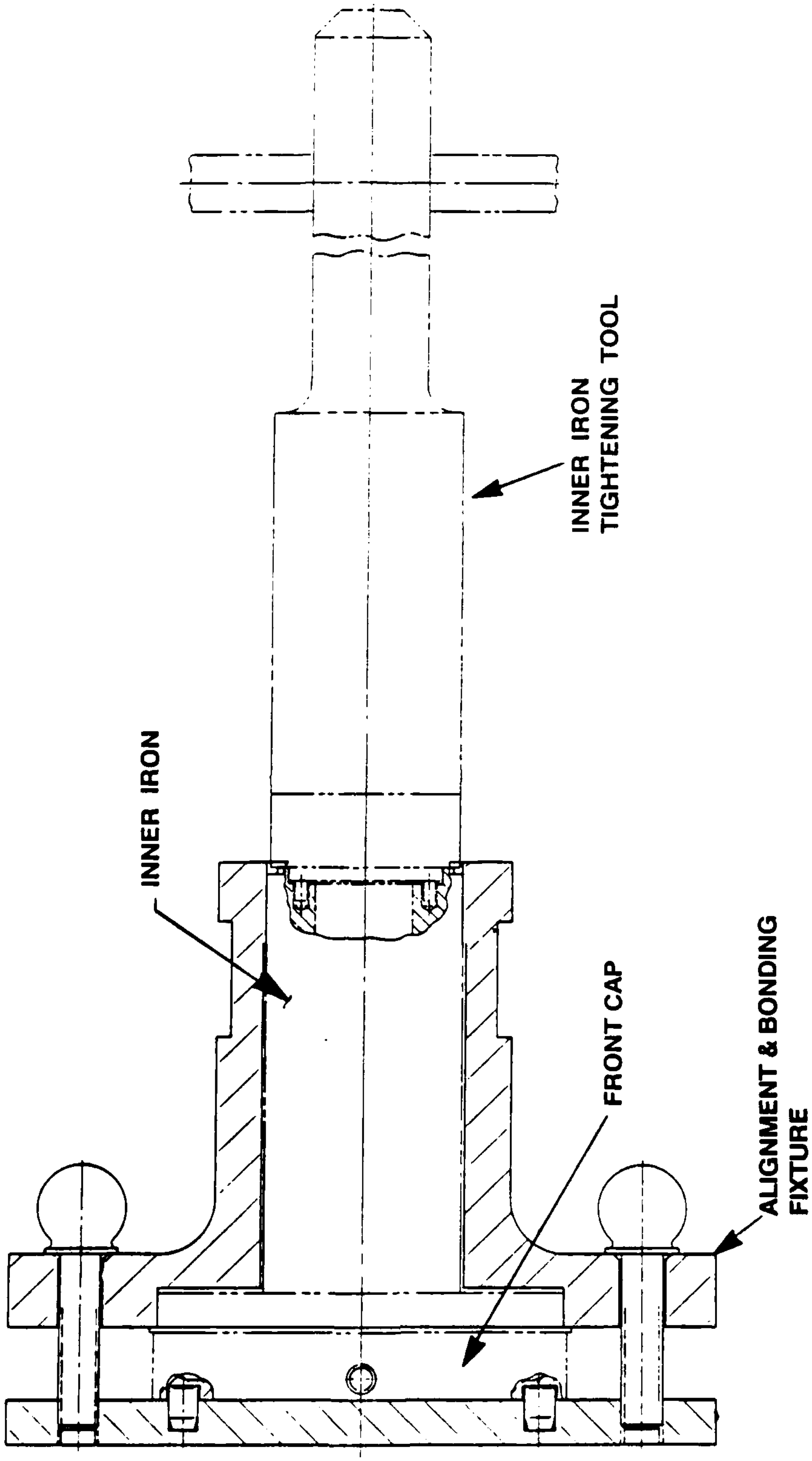


Figure 5.3-1. Front Cap/Inner Iron Alignment and Bonding Fixture

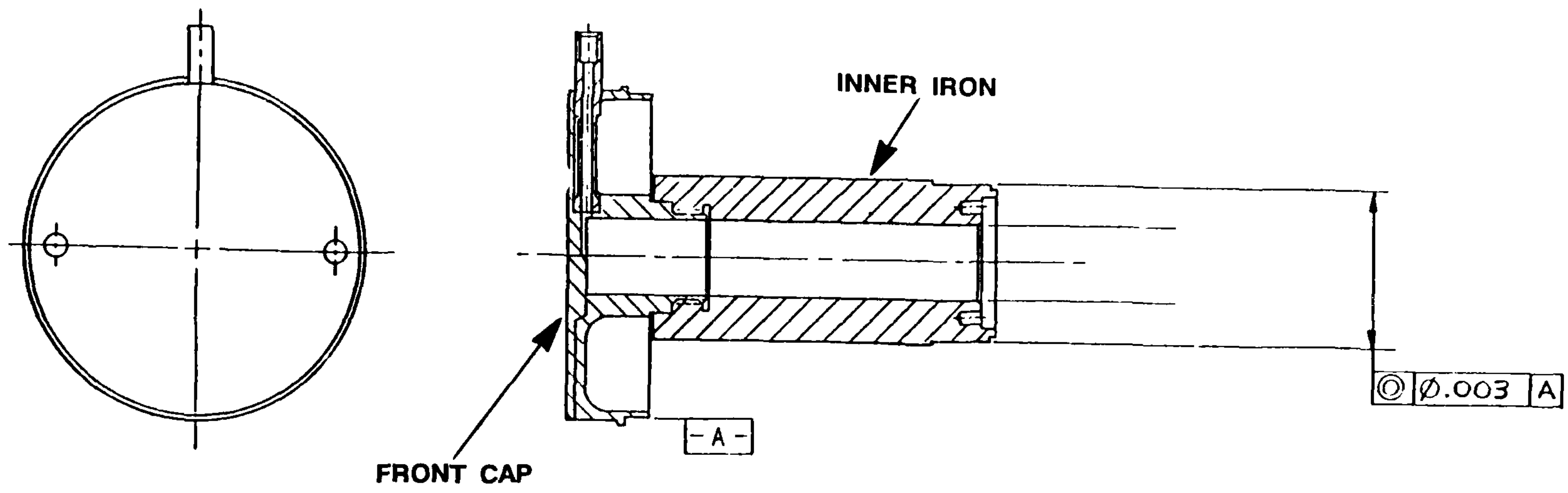


Figure 5.3-2. Front Cap/Inner Iron Subassembly

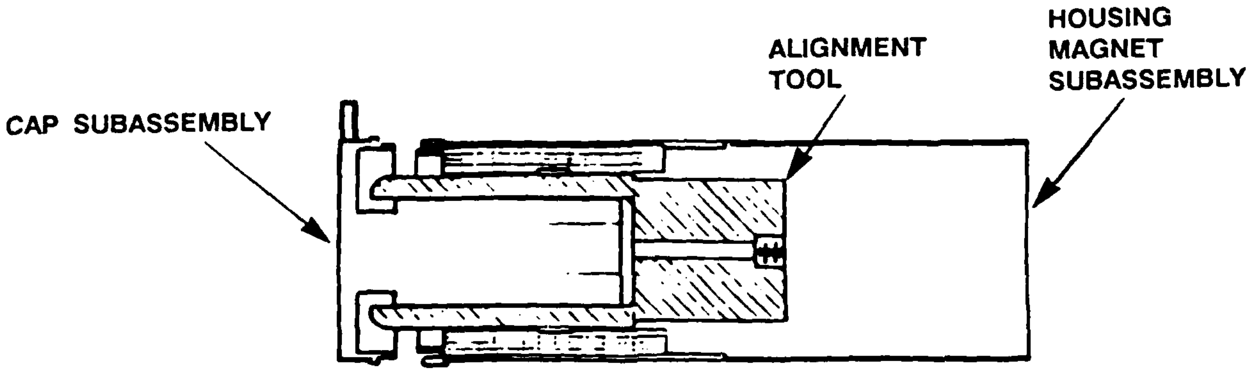


Figure 5.4-1. Housing Magnet and Cap Subassembly with Alignment Tool in the Piston

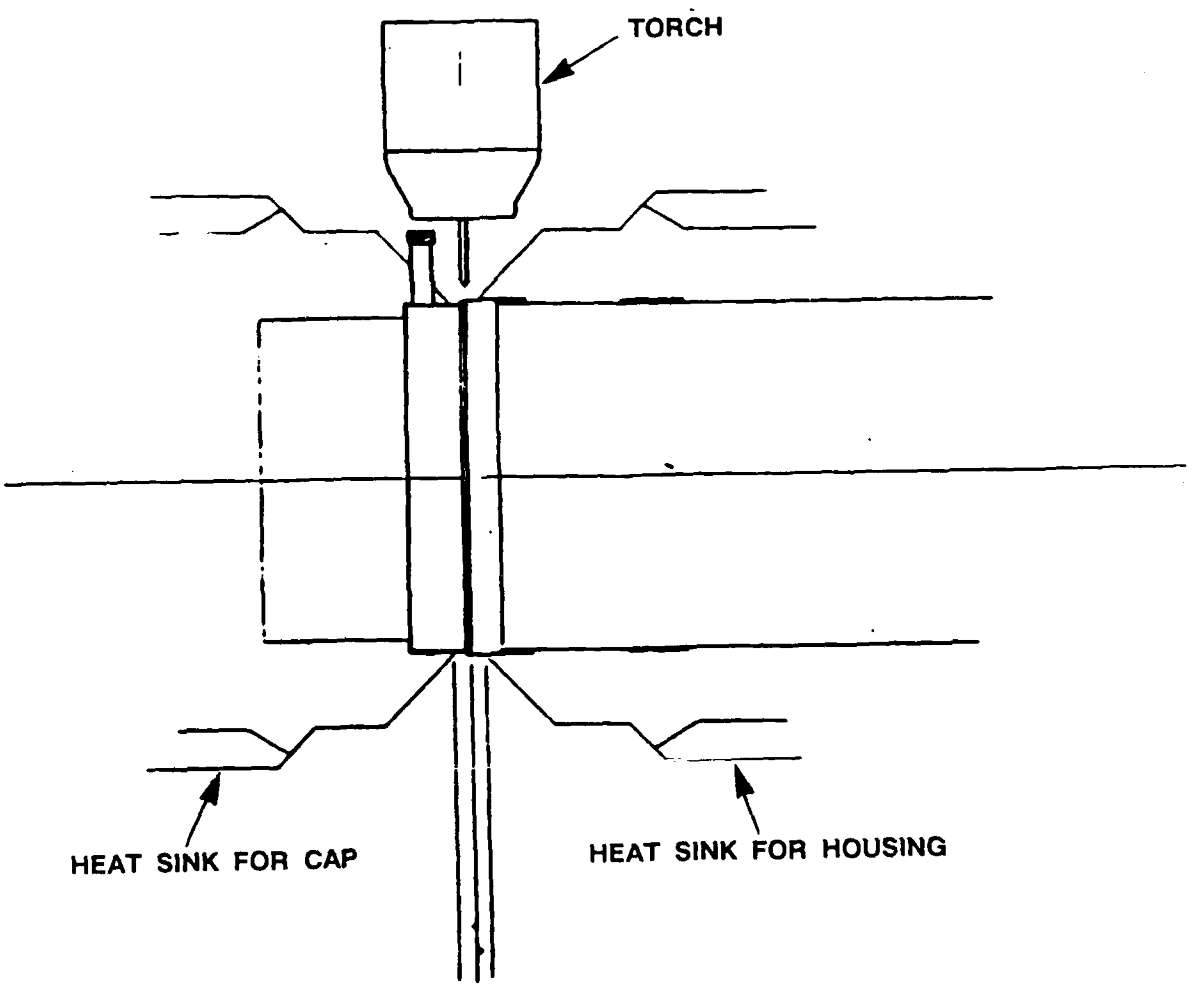


Figure 5.4-2. Housing Subassembly with Heat Sinks Ready for TIG Welding

j) Remove the assembly from the lathe and clean the welded area using a stainless steel brush or silicon carbide paper. Remove the plug from the union tube.

5.5 COIL WINDING ASSEMBLY

The following steps describe the procedure required to assemble the coil winding assembly.

Components: coil tray, copper wire, insulator, flex lead, Teflon tubing, varnish, cover plate and flat head screws

a) Clean the components thoroughly.

b) Apply insulation tape in two places as shown in Figure 5.5-1 and fasten spacers to the tray.

c) Slide the tray on the winding mandrel.

d) Start winding the coil without any slack with 15 turns per layer and wind 6 layers total.

e) Check that the outside diameter of the coil is less than the design maximum.

f) Mask the exposed areas of the assembly using a masking compound.

g) Dip the coil assembly into a container filled with Scotch Resin - 250 for 15 minutes under vacuum. Remove the coil after impregnation and wipe off the excess epoxy.

h) Oven cure the epoxy.

j) Remove the Teflon mandrel spacer and the masking compound.

k) Strip and tin both ends of copper wire. Solder the flex leads to the copper wire. Position the shrink sleeve over the soldered joints and apply heat to shrink them. Assemble the Teflon tube over the flex leads.

l) Vacuum bake the assembly.

5.6 COIL AND VIBRATION ABSORBER ASSEMBLY

The following steps describe the procedure required to assemble the coil and vibration absorber assembly.

Components: piston subassembly, coil subassembly, vibration absorber subassembly, spool, flex leads and flat leads

a) Thoroughly clean and vacuum bake all the components.

b) Install the flex lead into the coil tray groove followed by filling the groove with RTV as shown in Figure 5.6-1. Position the cover plate over the coil and fasten it to the coil using two

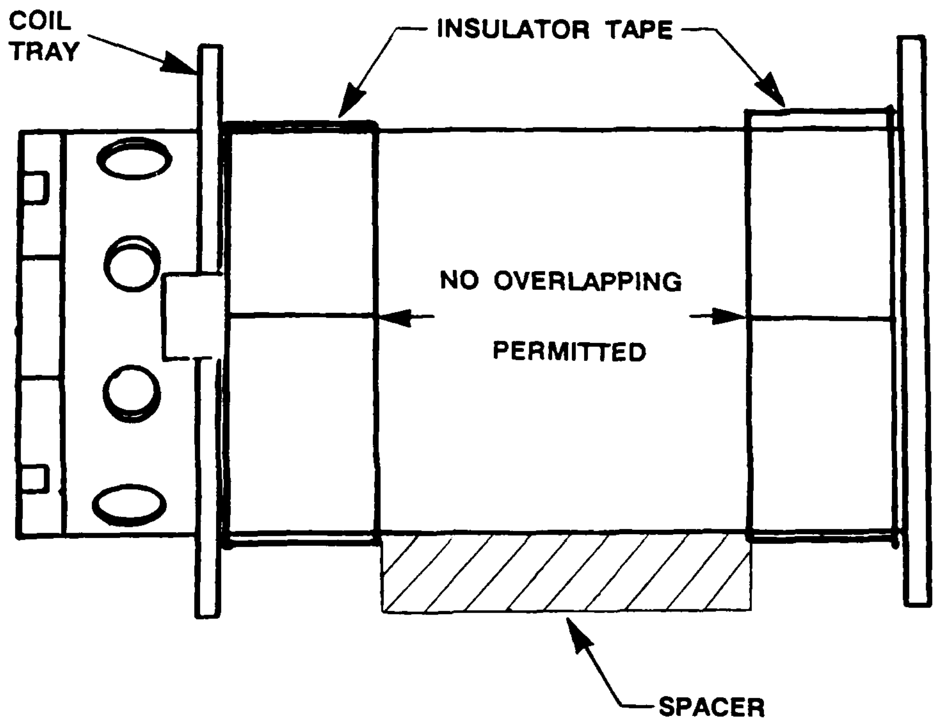


Figure 5.5-1. Coil Tray with Insulation Tape Applied Two Places

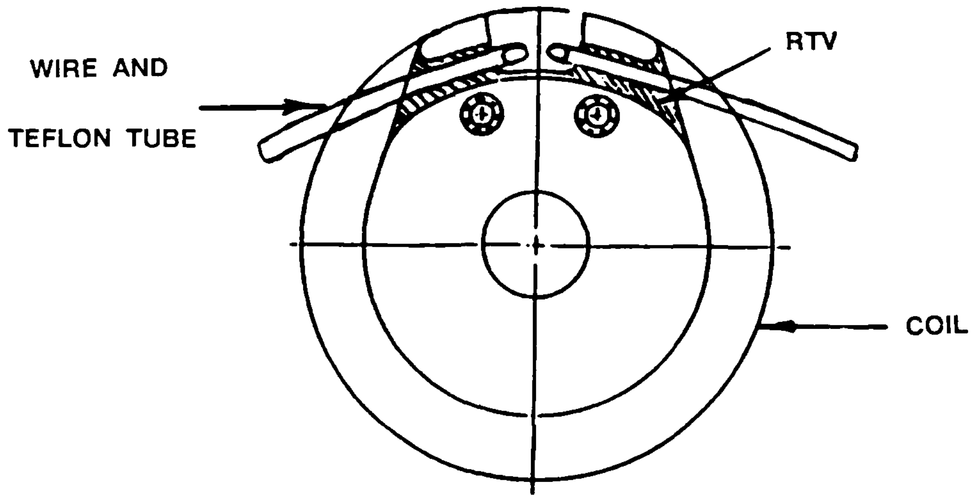


Figure 5.6-1. Coil Winding Assembly Depicting Flex Leads in Position with Potting Compound

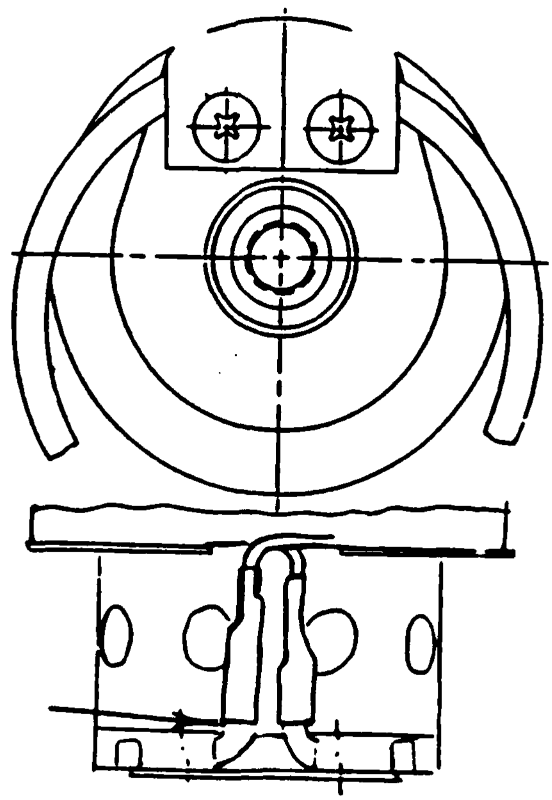


Figure 5.6-2. Coil Winding Plate with Cover Plate Installed

screws with Loctite applied. The RTV shall be cured at room temperature. See Figure 5.6-2.

c) Fasten the piston and the coil assembly using the piston spool and applying Loctite. Figure 5.6-3 shows a piston alignment tool in place before the spool is tightened.

d) Assemble the centering spring of the vibration absorber assembly onto the spool. Adjust the number of spring-turns engaged onto the spool to achieve the specified overall length. See Figure 5.6-4.

e) Secure the flex leads at the wire clamp by crimping it while making sure that the flex leads are contained well within the outside diameter of the vibration absorber.

f) Solder two flat leads to the flex cables. Place the flat leads in the grooves of the vibration absorber and secure them using Loctite.

g) Clean and vacuum bake the assembly.

5.7 DRIVER ELECTRONICS ASSEMBLY

The following steps describe the procedure required to assemble the driver electronics assembly.

Components: power hybrid, inverter hybrid, filter board, epoxy, heat sink

CAUTION

Perform the assembly at a static safeguarded work area which is capable of controlling static charge on conductive materials, people and nonconductive materials. In addition transport all static-sensitive components in static shielding containers or packages.

a) Assemble the power hybrid and the inverter hybrid until the socket shoulder bottoms out on the substrate.

b) Line up the pins from the hybrid assembly with the filter board socket and press the filter board onto the hybrid until the shoulder bottoms out. Make sure that overall height meets the specification limits.

c) Remove the filter board from the subassembly. Select R2 from the resister kit and solder it onto the filter board to achieve the specified output voltage. Clean the filter board and reassemble

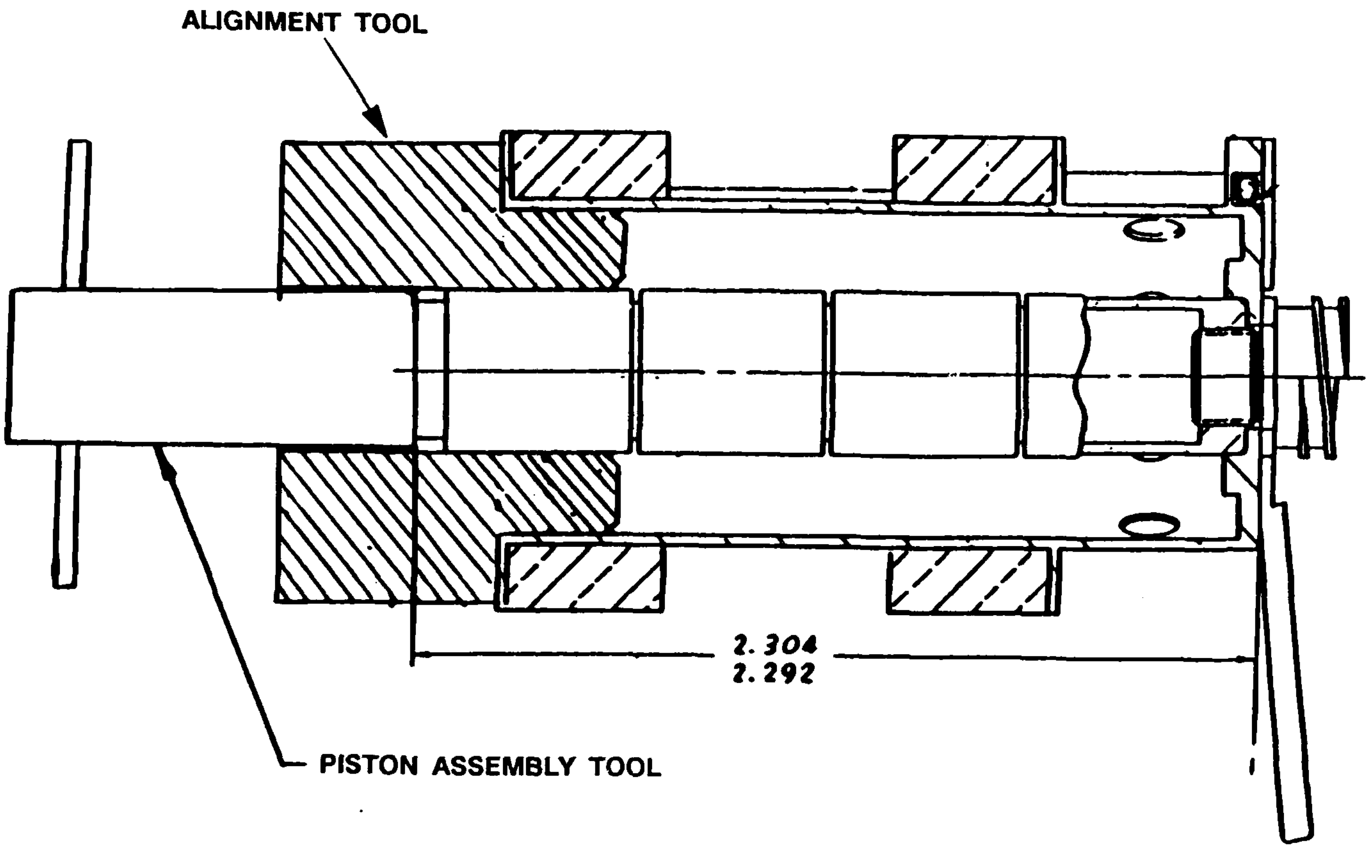


Figure 5.6-3. Piston Coil Assembly with Alignment Tool in Position

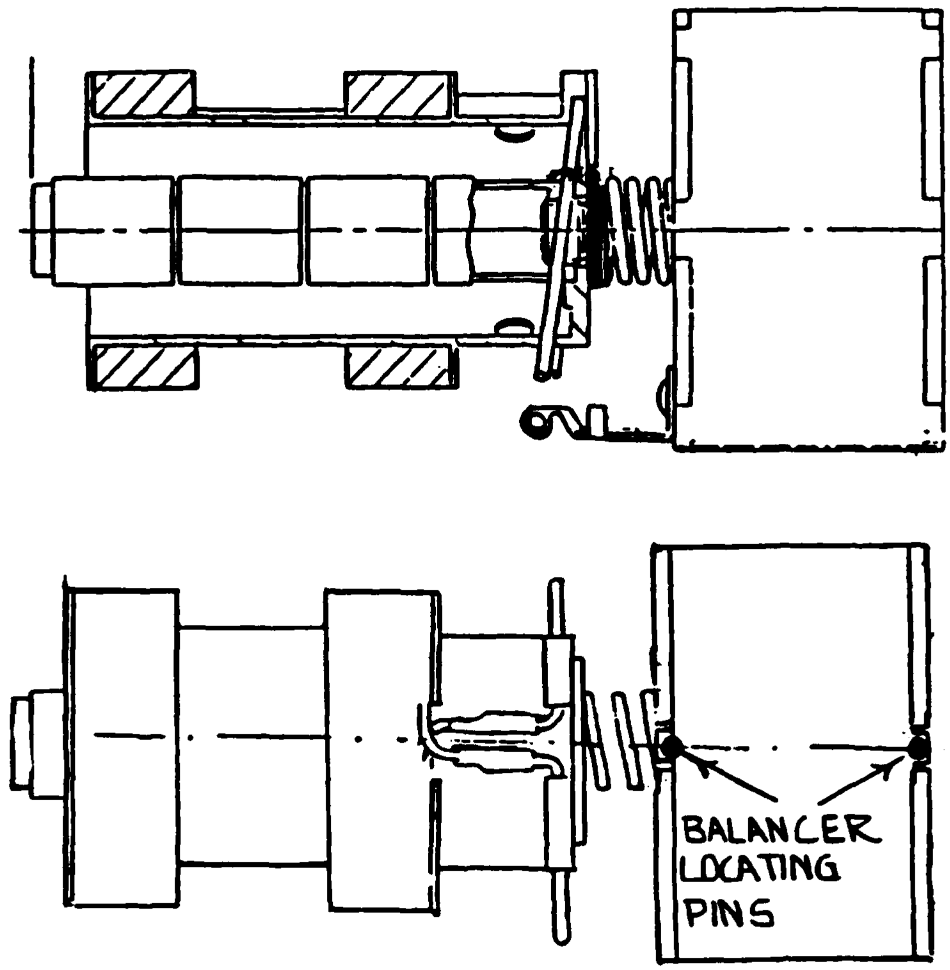


Figure 5.6-4. Piston Coil Balancer Assembly

it onto the hybrid and make sure that the overall height meets the specified limits (see Figure 5.7-1).

d) Clean the hybrid heat sink thoroughly. Apply epoxy on the bottom surface of the power hybrid and place it inside the heat sink with the specified orientation. Make sure that the pin/sockets at the bottom of hybrid are centered in the holes of the heat sink.

e) Clean the bottom of the heat sink. Place three O-rings in the locating holes and apply epoxy (see Figure 5.7-2).

f) Cure the epoxy bonds in an air oven. Vacuum bake the assembly and store in a vacuum or desiccator.

5.8 COOLER FINAL ASSEMBLY

The following steps describe the procedure required to complete assembly of the cooler.

Major Components

Transfer tube, housing subassembly, guide ring sleeve, spacers, end cap assembly, cold-finger assembly, displacer assembly, cap assembly, electronic subassembly, coil and vibration absorber assembly, cold finger protective sleeve and name plate.

a) The piece parts must be cleaned thoroughly and vacuum baked. The individual subassemblies shall continue to remain in the vacuum bake oven until needed for further processing.

b) Clamp the cooler housing subassembly on the bell jar base of the RF brazing equipment. The union should be positioned inside the RF brazing coil. Slide the brazing pre-form onto the transfer tube end to be brazed. The transfer tube is then inserted into the union while making sure that the pre-form rests on the shoulder of the union tube.

c) Carefully place the bell jar in position over the assembly and plate. Evacuate the bell jar until the high vacuum gauge reads 5×10^{-5} torr or lower. Braze the subassembly using the instructions specified for the RF brazing equipment in use. Allow the assembly to cool before venting the bell jar. Remove the assembly carefully and remove the RF coil.

d) RF braze the other end of the transfer tube to the warm end flange by following steps b and c.

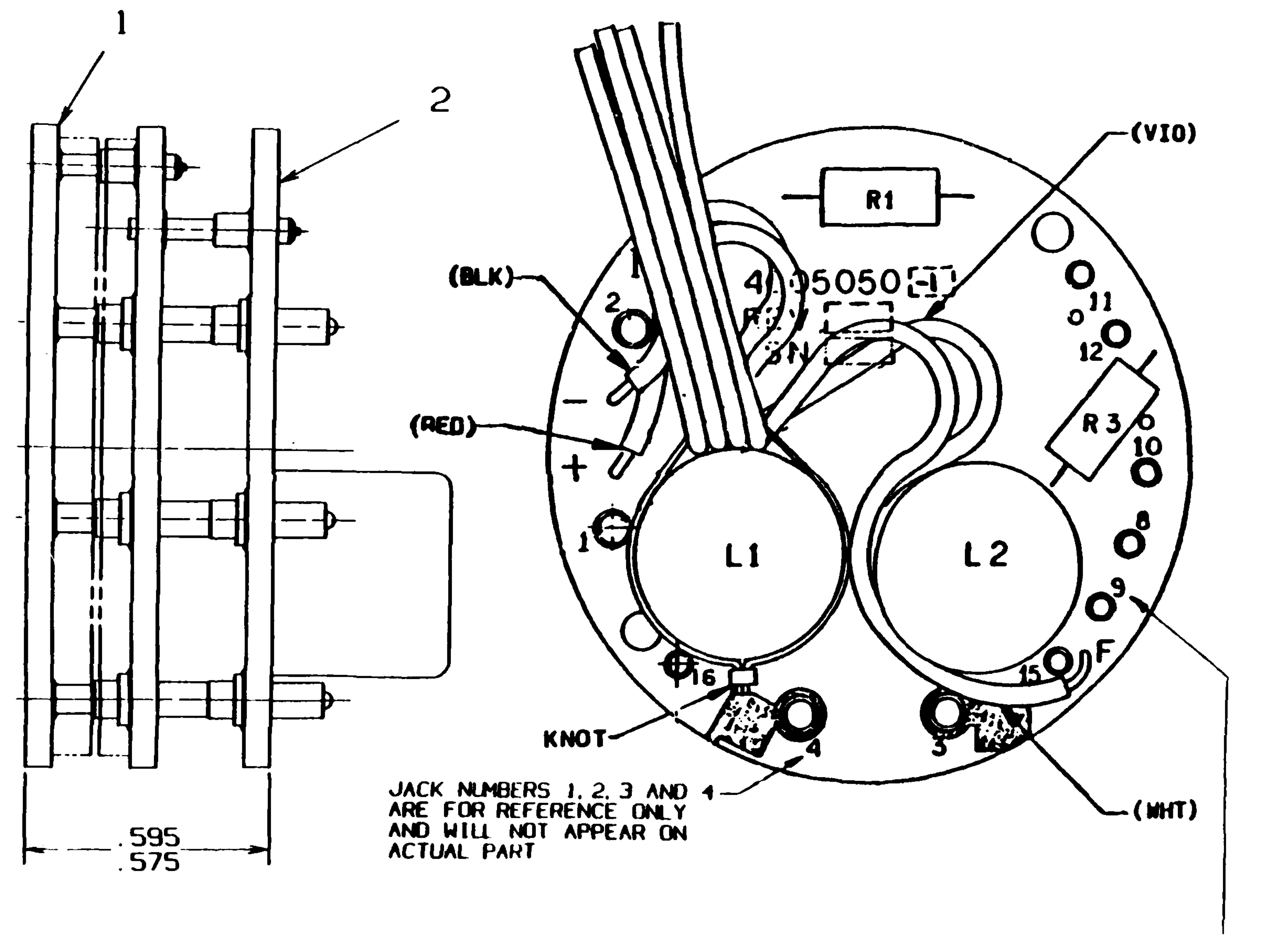


Figure 5.7-1. Power, Inverter and Filter Board Assembly

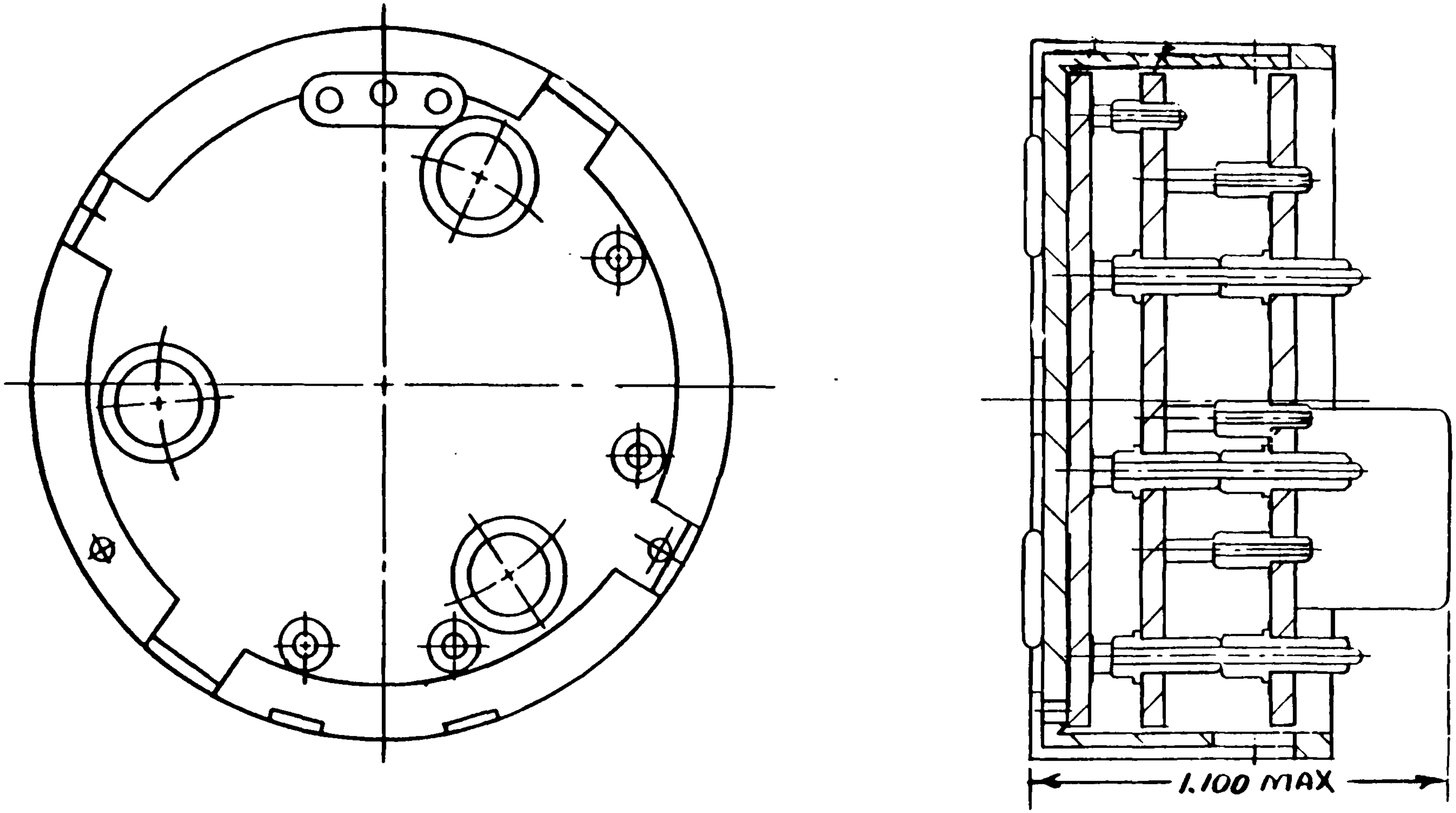


Figure 5.7-2. Driver Electronics Subassembly

e) Place the guide ring in the groove of the displacer subassembly front cap. Assemble the expander subassembly using all the piece parts and subassemblies shown in Figure 5.8-1. Use shims as required to achieve the specified displacer front space.

f) Assemble the piston-coil-vibration absorber subassembly in the compressor housing assembly as shown in Figure 5.8-2 and achieve the specified piston front space. Add spacers as required to the piston coil assembly as shown. Make sure to reapply thread adhesive to the piston spring anchor if the piston spring anchor has to be disassembled.

g) Assemble the electronic subassembly into the compressor housing making sure the two coil wires are routed through the two elliptical holes provided in the heat sink. In addition, the dowell pin provided in the vibration absorber assembly must mate with the hole in the heat sink.

h) Solder the two leads from the motor coil to the filter board. Solder the red, black and white wires to the end cap header. The violet wire is soldered to the terminal on the end cap. See Figure 5.8-3.

i) Install spacers with the required thickness so that when the cap is installed into the compressor housing the TIG weld lips line up within 0.002".

j) Select a spacer with the required thickness and bond it to the end cap to achieve .005" to .010" clearance between the top surface of the inductor and the spacer as shown in Figure 5.8-4.

k) Using an o-ring and the assembly fixture, assemble the compressor as shown in Figure 5.8-5. Purge and charge with helium at the specified pressure. Apply 17 Vdc to the cooler and run it for a minimum period of 16 hours. Stop the test and conduct performance tests at all ambient temperatures to make sure that the cooler meets the specification requirements. Release the pressure, remove the assembly fixture and discard the o-ring.

l) The assembly is now ready for TIG welding. Clean the TIG weld lip areas of the cap and housing body. The surfaces must be bright and free from any oxide or burrs. Adjust the orientation of the end cap assembly so that the feedthrough slot is lined up with the

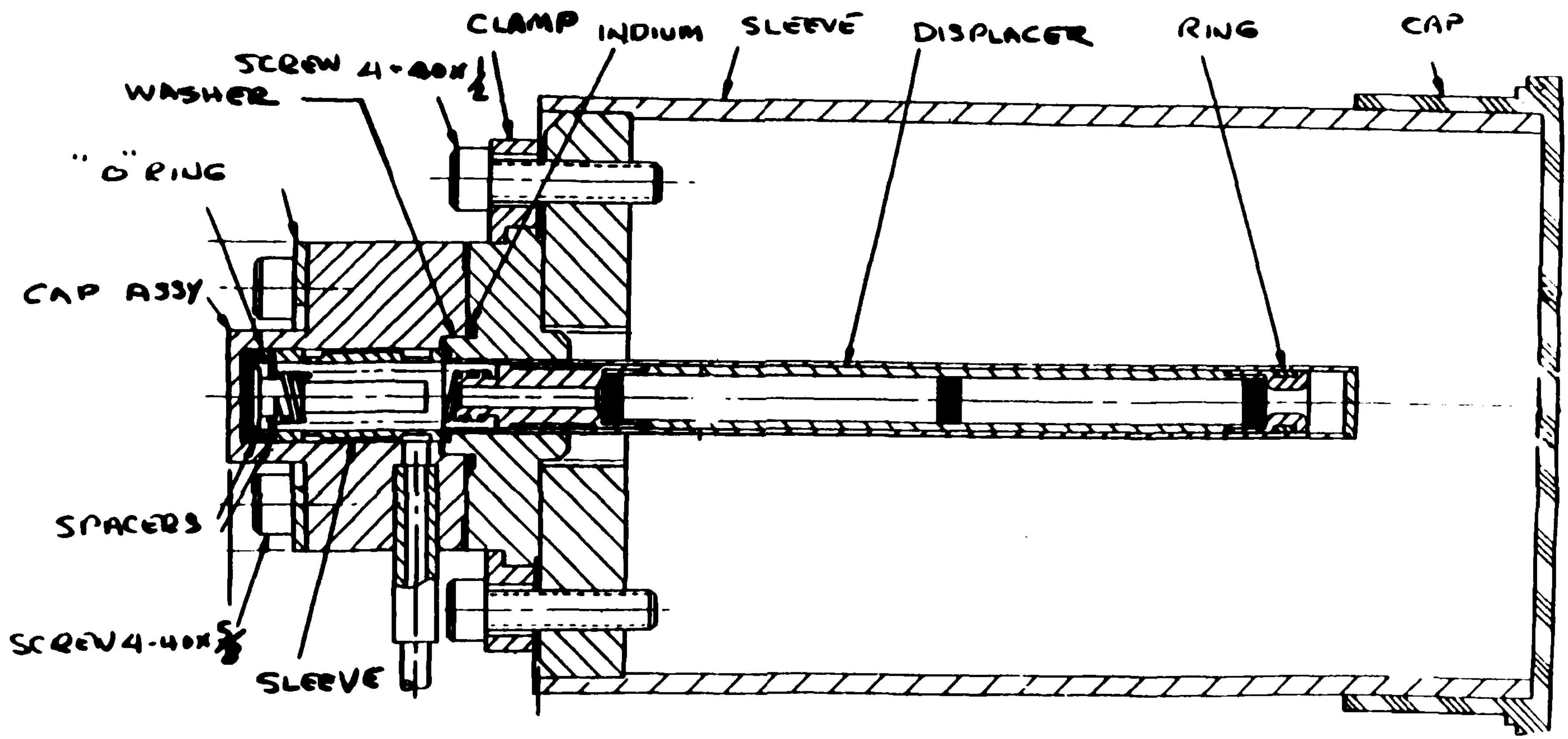


Figure 5.8-1. Expander Subassembly

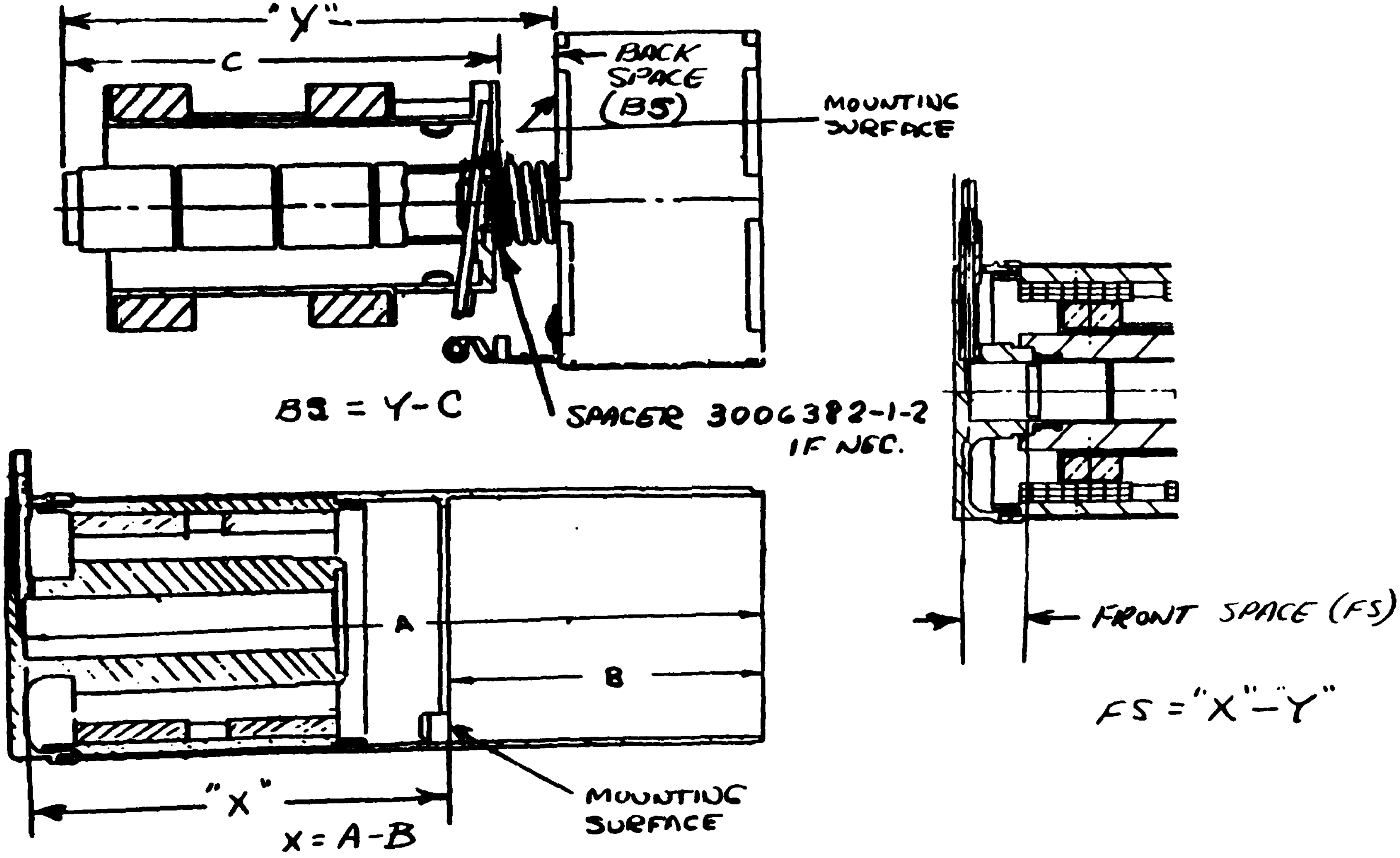


Figure 5.8-2. Compressor Vibration Absorber Subassembly

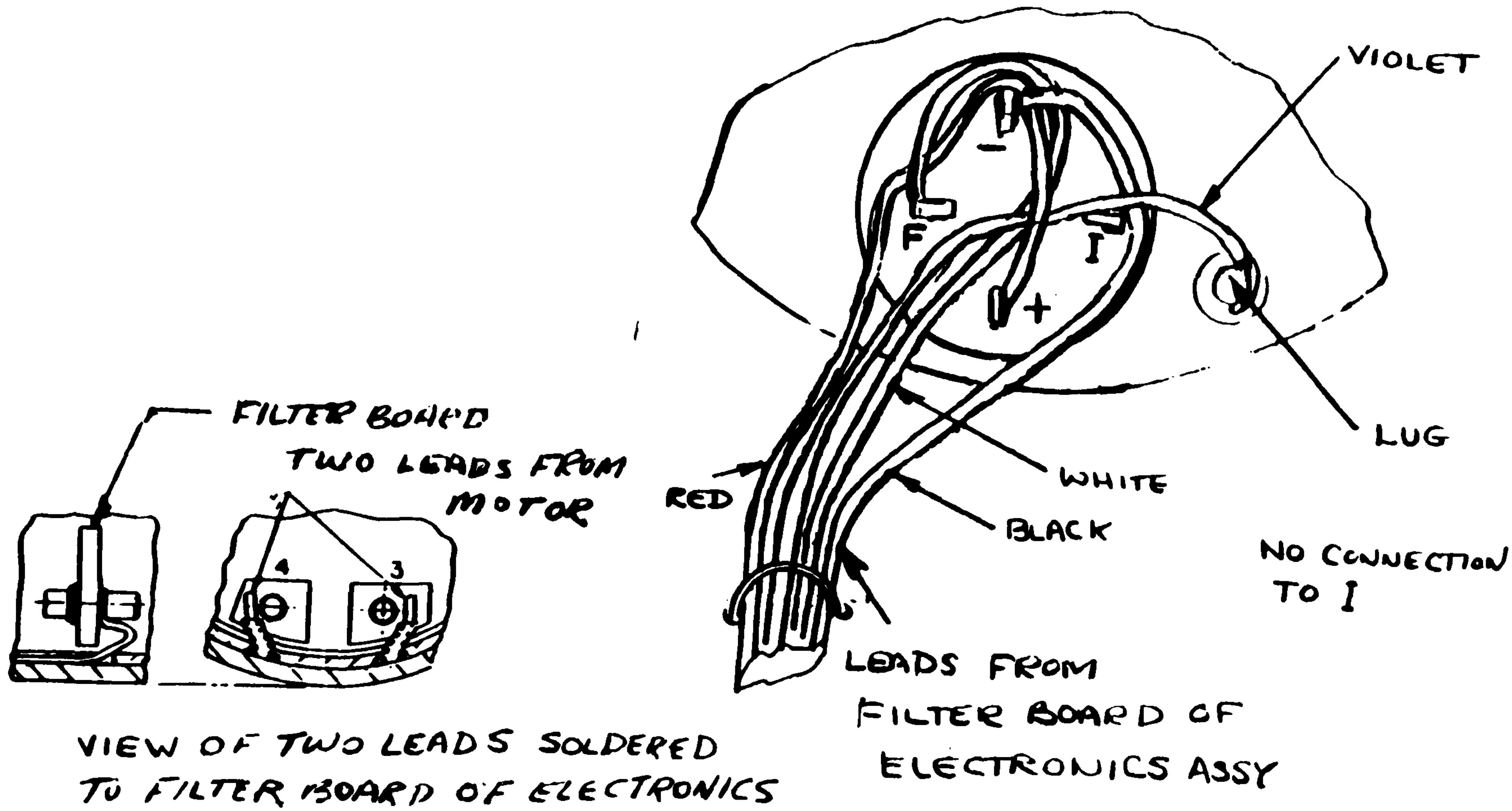


Figure 5.8-3. Soldering of Driver Electronics into the Compressor

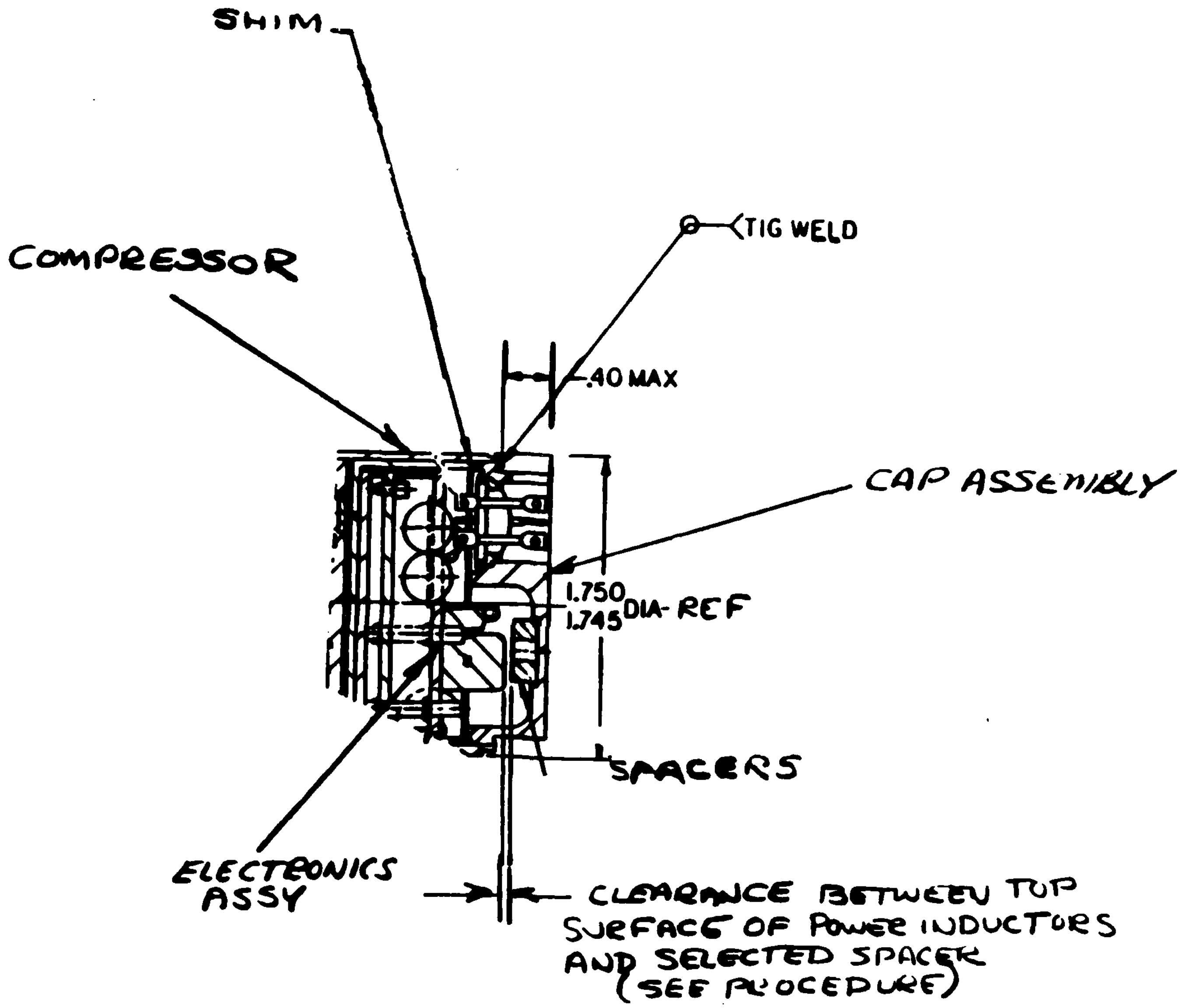


Figure 5.8-4. Bonding Selected Spacers to Cap

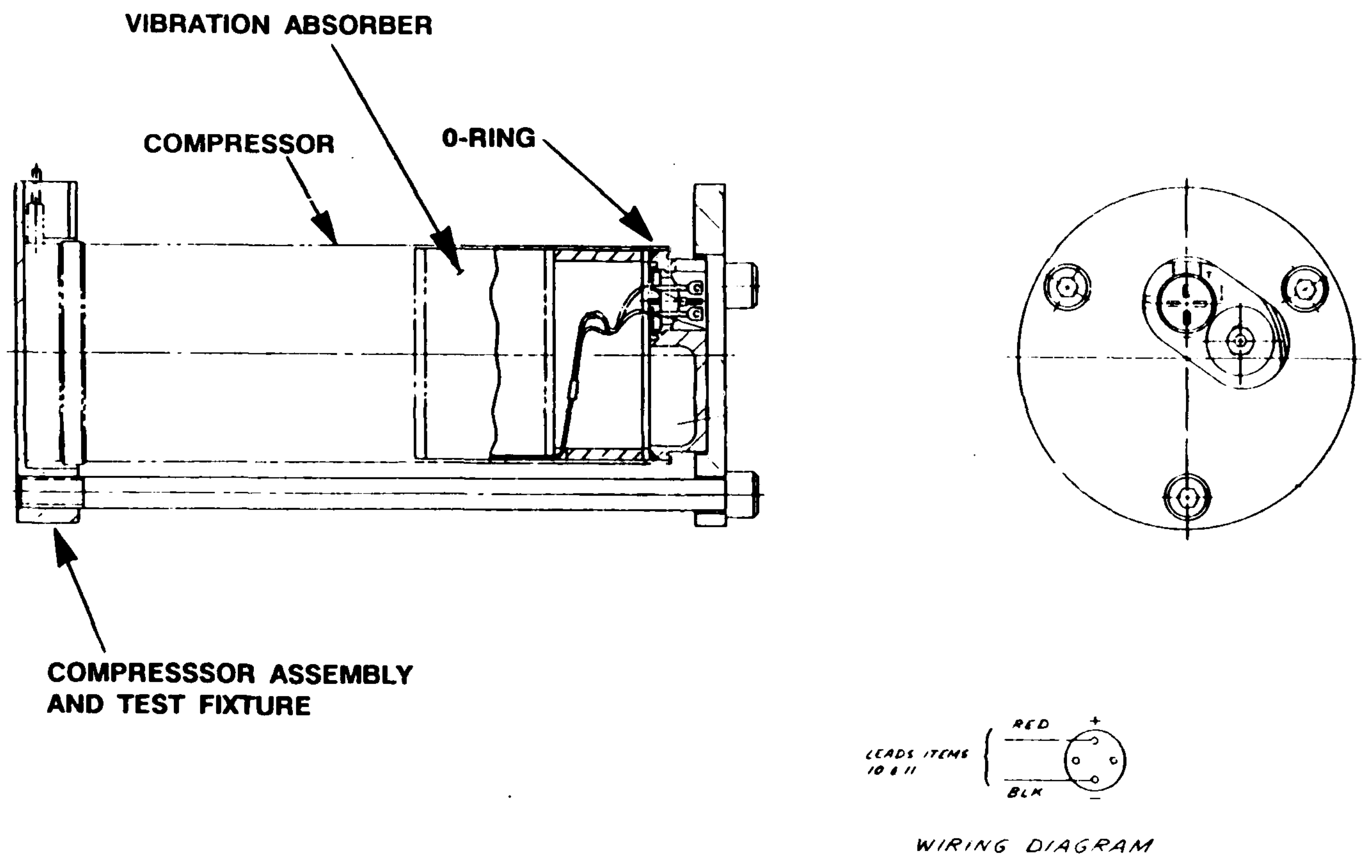


Figure 5.8-5. Compresor Mounted in Test Fixture for Run-in and Performance Tests

transfer tube. Vacuum bake the assembly for at least 16 hours.

m) Assemble the heat sinks onto the compressor body end cap subassembly as shown in Figure 5.8-6 and weld the subassembly using the procedure outlined in paragraph 5.4. Figure 5.8-7 shows the completed compressor subassembly.

n) Purge and charge with helium at the specified pressure. The helium leak rate from the assembly must be less than the specification limits.

o) Strip and tin the power leads. Wrap and solder the red wire to the + terminal, the black wire to the − terminal and the white conductor to the **F** terminal. The green conductor is not connected. Slide the shrink sleeve over the power cable and wrap its slotted ends around the terminals. Apply heat from a heat gun and shrink the sleeve. The header is potted with the specified compound and cured. Trim away all excess compound.

p) Clean the exterior of the compressor, expander and nameplates.

q) Conduct the acceptance test procedure to meet the specification requirements.

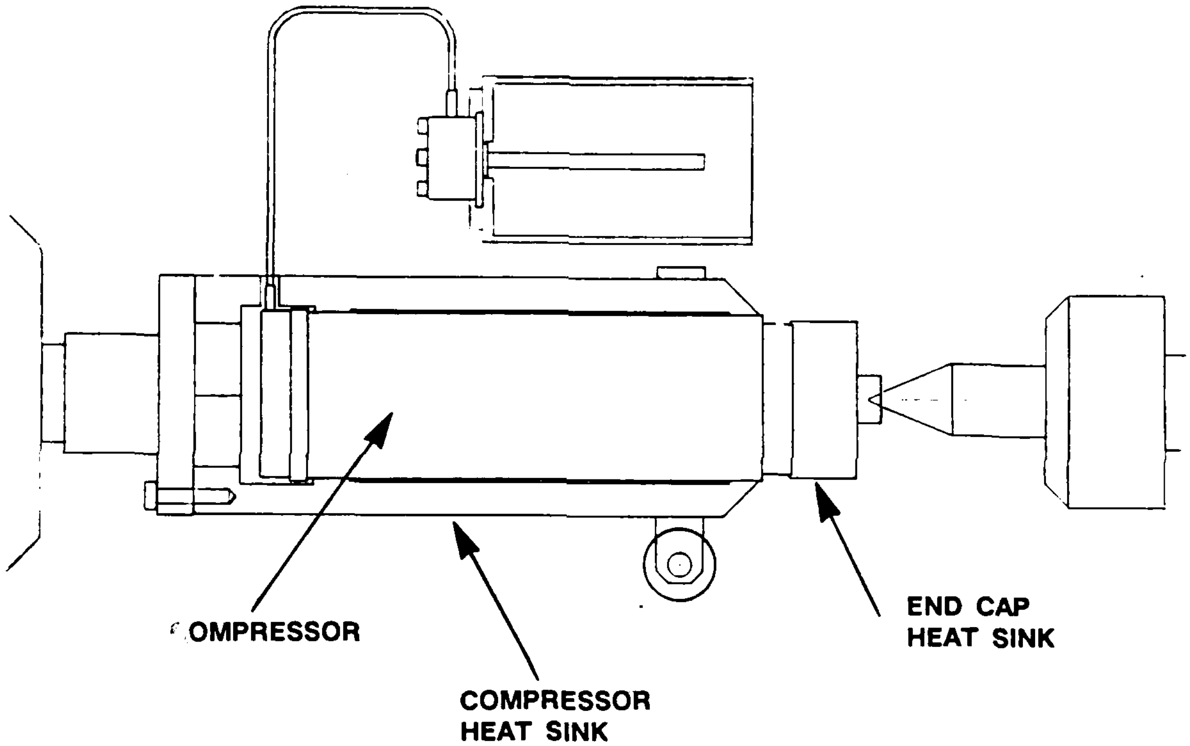


Figure 5.8-6. Compressor with Heat Sink Mounted on Lathe for Welding Rear Cap

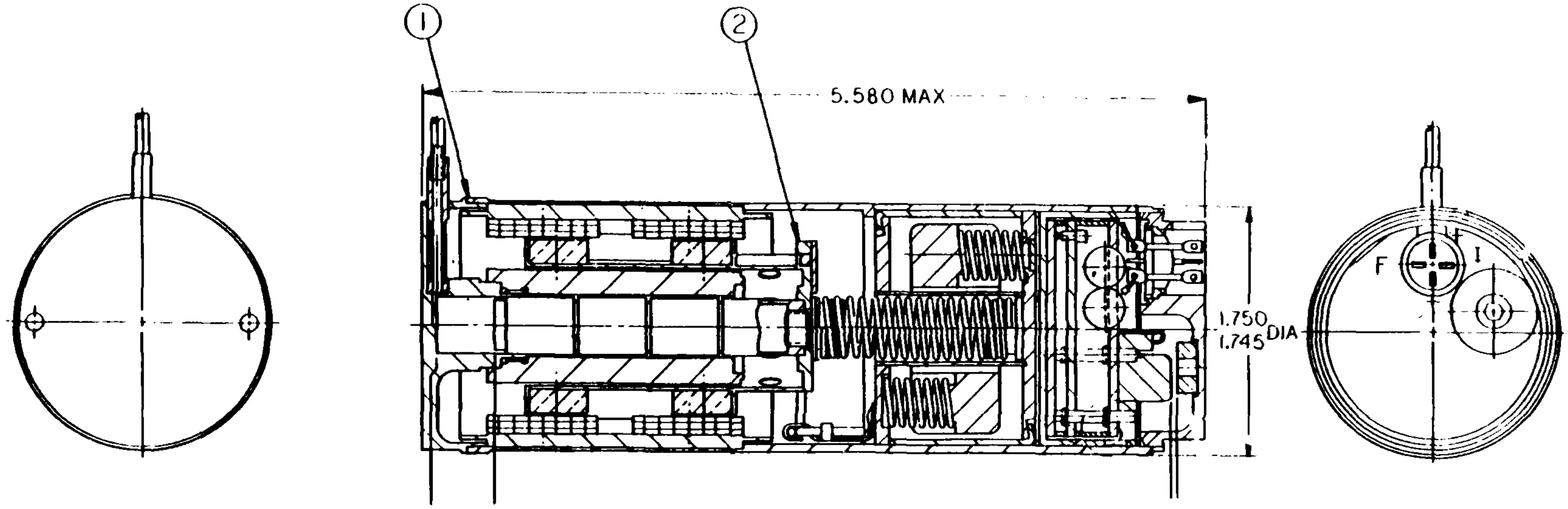


Figure 5.8-7. Complete Compressor Subassembly

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Performance within or exceeding the technical requirements established were demonstrated with minor exceptions. The capability of the cooler to meet the key reliability requirement was demonstrated, as was its ability to meet the stringent cooling performance, efficiency and weight objectives. The cooler proved its durability by passing all thermal and mechanical environmental tests. The EMI emanations from the cooler were demonstrated to be far lower than those of any prior cooler with internal cooler electronics. Small deviations were noted from the design requirements at only two test conditions. Similarly, the audible noise emanations from the cooler were demonstrated to be far lower than those of any prior cooler. A small deviation from the requirement was observed at the 8,000 Hz center frequency on two units.

Hence, a reliable, producible, linear-drive split-Stirling cooler is now a reality.

6.2 RECOMMENDATIONS

It is recommended that the Government continue funding of linear resonant Stirling cycle cooler development with the objective to reduce output vibration, further increase reliability, and reduce manufacturing costs.